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Techniques for Preparing Flowchart-Format Emergency Operating Procedures

Background (Sections 1.0-9.0)

Prepared by V.E. Barnes, C.J. Moore, D.R. Wieringa,
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ABSTRACT

This two-volume report describes the activities, findings, and recommendations of a project entitled "Techniques for Presenting Flowchart-Format Emergency Operating Procedures." The project team surveyed the literature pertaining to flowcharts, reviewed existing flowchart emergency operating procedures (EOPs), interviewed consultants who produced flowcharts, and interviewed reactor operator licensing examiners about the use of flowcharts in nuclear power plants.

Volume 1 of this report discusses the use of flowchart-format EOPs in nuclear power plants and presents issues to be addressed in the design and implementation of flowchart EOPs. Volume 2 presents techniques for preparing flowchart EOPs that were derived from the information discussed in Volume 1 and from NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982).

EXECUTIVE SUMMARY

The two volumes of this report discuss the flowchart-format emergency operating procedures (EOPs) used in nuclear power plants. Volume 1 discusses design principles and implementation issues that should be considered in preparing flowchart EOPs. Volume 2 presents techniques for designing and implementing flowchart EOPs that are derived from the principles discussed in Volume 1.

Emergency operating procedures are "plant procedures that direct operators' actions necessary to mitigate the consequences of transients and accidents that have caused plant parameters to exceed reactor protection system set points or engineered safety feature set points, or other established limits" (USNRC, 1982, p. 3). Historically, EOPs have been presented in text format as a series of steps. Recently, however, many licensees have begun to present their EOPs as flowcharts.

Flowcharts are a means of presenting a procedure by combining text with graphics. This report considers two types of flowcharts: (1) algorithmic flowcharts, which are flowcharts as we usually consider them; and (2) big-picture flowcharts, as they are known in the industry, which are a hybrid of a traditional flowchart and a text procedure. Big-picture flowcharts have evolved in the nuclear power industry in response to the need to present multiple procedures that must be performed concurrently.

Traditional algorithmic flowcharts and three variations on the traditional format are discussed: (1) logic trees, (2) Nassi-Schneiderman flowcharts, and (3) nested boxes. The traditional flowchart uses symbols of various shapes as boxes that enclose small bodies of text. The shape of the symbol indicates the type of text that is enclosed in the box; for example, decision steps are phrased as questions and enclosed in a diamond, and action steps are enclosed in a rectangle. These symbols are connected by lines, called flowlines. Users follow a flowpath through the flowchart and perform steps as they are encountered. Flowpaths divide at decision symbols--typically into two flowpaths, one if the answer is yes, one if the answer is no--but can merge later in the flowpath.

Logic trees are very similar to traditional flowcharts, except that flowpaths do not merge. Thus, a logic tree grows wider from beginning to end, as flowpaths divide at decision symbols and do not merge again. Logic trees are most commonly used for diagnostic procedures, which contain many questions and few action steps. Because their flowpaths do not merge, logic trees for complicated procedures would be large and unwieldy.

Nassi-Schneiderman flowcharts excel at showing the hierarchical relationships that are not evident in traditional flowcharts and logic trees. The most striking feature of the Nassi-Schneiderman flowchart is that it does not contain flowlines; instead it consists of a series of boxes, stacked or set one inside the other. All boxes share a common right border. Boxes that are stacked indicate steps that are performed sequentially. If boxes are nested inside each other, the outermost box is a loop, indicating that the steps in the inner boxes are to be repeated.

Nested-boxes flowcharts are quite similar to Nassi-Schneiderman flowcharts. However, the boxes are nested completely inside each other and do not share a common border.

Although Nassi-Schneiderman and nested-boxes flowcharts show hierarchical relationships well, they do not present referencing and branching information well and can be visually dense and difficult to follow. For these reasons, they are not well-suited for the presentation of EOPs.

Consequently, the algorithmic flowcharts used in the nuclear power industry are either of the traditional or logic tree format. Several studies have indicated that algorithmic flowcharts are an aid to decision-making; reactor operators using algorithmic flowcharts ought to make fewer errors than those using text procedures if the task requires many decisions. However, algorithmic flowcharts have disadvantages when used in the nuclear power industry: (1) algorithmic flowcharts are not the best format for presenting a procedure that contains many actions and few decisions; (2) the situation in a nuclear power plant can be so complicated that it will not lend itself well to a rigid algorithmic analysis; (3) algorithmic flowcharts divide decisions into such simple steps that the relationship between these steps is not evident; and (4) when broken down into true algorithms, flowcharts quickly become cumbersome and difficult to use. Because of these deficiencies, algorithmic flowcharts should only be used in situations where their advantages as decision aids outweigh any drawbacks. Two such situations are diagnostic flowcharts, which would refer operators to text EOPs once the problem was diagnosed, and the Critical Safety Function Status Trees used in Westinghouse plants.

Big-picture flowcharts are used primarily by members of the General Electric (GE) Boiling Water Reactors (BWR) Owners' Group and were developed in response to this owners' group's philosophy of emergency event mitigation, which requires operators to execute several procedures concurrently. Operators using text procedures based on the GE BWR Owners' Group's emergency procedure guidelines encountered severe placekeeping difficulties. Big-picture flowcharts, which present the procedures that are to be executed concurrently side-by-side on a large sheet of paper, are a solution to these placekeeping problems. Big-picture flowcharts are a hybrid of text and flowchart. Because a simple graphic presentation is important in big-picture flowcharts, many of the attributes of algorithmic flowcharts, which simplify decision-making but are graphically complicated, cannot be used in big-picture flowcharts. Thus, big-picture flowcharts are not decision aids. Big-picture flowcharts are easier to use than equivalent text procedures, but are not a complete solution to the difficulties that may arise when operators are required to perform several tasks at once.

Several principles of graphic design are important to the preparation of effective flowcharts. These principles were derived from the literatures on flowchart design, graphic design, cartographic design, and cognitive psychology, and from interviews with flowchart designers. Flowcharts should be designed according to the principles of contrast, unity, proportion, rhythm, simplicity, and consistency. In following these principles, the flowchart designer must effectively manipulate the visual variables of position, implied movement, shape, orientation, size, value, color, and texture. For example, the variation of value--that is, lighter and darker shades--provides the contrast that is essential to pick out an entry point in a cluttered flowchart. The use of the same shape to enclose the same type of information provides the consistency that enables users to always recognize the meaning of that symbol. Effective use of position and implied movement--that is, the placement of symbols and the flowlines that connect them--can make a complicated flowchart much easier to understand.

Flowchart layout is facilitated by using basic flowcharting structures: linear, alternative, repetitive, divergent, case, bypass alternative, decision-follows-the-action, and abnormal-exit. Basic structures are the combinations of flowlines and symbols that make up a flowpath. Using only the basic structures, flowchart designers can create any logical sequence of steps. These structures should be used at several levels; for example, a repetitive structure can become part of a larger alternative structure. If flowchart designers construct flowcharts by nesting the basic structures in this manner, the overall organization of the flowchart will be apparent to the designers and to the users of the flowchart.

Flowchart designers must keep other principles in mind when designing a flowchart. The design of the flowchart must not create any visual illusions, such as figure/ground illusions, in which items in the background appear as items in the foreground. The flowchart should not be so complex that important information is not apparent to users. Type in the flowchart should be readable at the distance from which the flowchart will be read and under the lighting conditions in the control room, including degraded lighting. Decision tables should be used to simplify the logic in big-picture flowcharts. The level of detail in the flowchart, which is often less than in a corresponding text procedure, should not be so low that newly certified operators will not understand the procedure. Operator training programs must specifically address the low level of detail in flowcharts. The problems caused by using large flowcharts in a small control room should be addressed, as should the problems that will be encountered when producing and revising graphically complex flowcharts.

Specific techniques for flowchart designers are presented in Volume 2 and were derived from the design principles and other considerations discussed in Volume 1 of the report. These techniques are intended to assist flowchart designers in integrating and applying the complex considerations that must be addressed to prepare usable flowchart EOPs. However, because so little empirical research has been conducted to assess flowchart-format procedures, the techniques presented in Volume 2 should be viewed as hypotheses that await evaluation through further research and actual use of flowchart-format EOPs.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

The two volumes of this report discuss the flowchart-format emergency operating procedures (EOPs) used in nuclear power plants. Volume 1 discusses design principles and implementation issues that should be considered in preparing flowchart EOPs. Volume 2 presents techniques for designing and implementing flowchart EOPs that are derived from the principles discussed in Volume 1.

1.1 BACKGROUND

Emergency operating procedures are "plant procedures that direct operators' actions necessary to mitigate the consequences of transients and accidents that have caused plant parameters to exceed reactor protection system set points or engineered safety feature set points, or other established limits" (NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures, USNRC, 1982, p. 3). Standard prose, such as that in a novel or a newspaper, is a poor medium for presenting such procedural instructions (Davies, 1967; Wason, 1968; Wright, 1971; Wright and Reid, 1973; Krohn, 1983). Research has indicated that complex instructions written as prose are understood by readers only two-thirds of the time (Kammann, 1975). The problems with standard prose have led to the search for alternative formats for presenting the procedural instructions in EOPs. Historically, EOPs have been presented in text format as a series of steps. Recently, however, many licensees have begun to present their EOPs as flowcharts.

Flowcharts are a means of presenting a procedure by combining text with graphics. The written steps in a flowchart are usually connected by lines to form a flowpath. Users perform a procedure by following a flowpath and performing steps as they are encountered. These steps are typically enclosed in symbols that indicate the type of the step; for example, decision steps are commonly enclosed in a diamond-shaped symbol. There is no standard format for a flowchart, however: some flowcharts consist only of lines and include no symbols; others are entirely symbols and include no lines (Richards and Johnson, 1980). Flowcharts have been used for years by engineers and accountants, but they are most commonly used by computer programmers as a means of expressing computer code. The decisions, looping, and branching common in computer programs can be expressed in a relatively simple manner in a flowchart.

The increased use of flowchart EOPs is partially due to increased Nuclear Regulatory Commission (NRC) scrutiny of EOPs following the accident at Three Mile Island (TMI) in 1979. An NRC study of the EOPs at TMI (which were text procedures) concluded that the procedures "were deficient as aids to the operators primarily due to a failure to provide a systematic method of problem diagnosis" (Malone, Kirkpatrick, Mallory, Eike, Johnson, and Walker, 1980). The TMI Action Plan, Item I.C.9, "Long-Term Plan for Upgrading of Procedures," required the NRC to undertake a course of action to improve the quality of procedures in commercial nuclear power plants. This requirement led the NRC to establish requirements for EOPs, and to publish those requirements in NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982). In accordance with NUREG-0899 guidelines, licensees have developed plans for revising their EOPs, and these plans, called Procedure Generation Packages (PGPs), are being reviewed by NRC staff. A PGP consists of a writers' guide for EOP preparers, a method for converting the relevant Owners' Group generic technical guidelines to plant-specific guidelines, a description of the licensee's program for validating and verifying the revised EOPs, and a description of the program for training operators to use the revised EOPs.

In the course of reviewing PGPs, it became evident that the flowchart-format EOPs developed by some licensees in their EOP upgrade efforts were very different from text EOPs and could not be effectively evaluated using the criteria presented in NUREG-0899. Consequently, the present project was undertaken to establish a technical basis for evaluating flowchart-format EOPs and to provide information to licensees regarding techniques for developing usable flowchart procedures.

1.2 ORGANIZATION OF THIS REPORT

This report consists of two volumes. Volume 1 discusses the suitability of various flowchart formats for EOPs and principles that are relevant to flowchart design and implementation. Volume 2 presents specific techniques for the preparation and implementation of flowchart EOPs.

The material in Volume 1 provides the theoretical basis for the techniques described in Volume 2. Volume 1 is divided into eight sections. Section 2.0 explains the methodology used for this project. Section 3.0 describes various flowchart formats. Section 4.0 discusses graphics principles that should be considered in the design of flowchart EOPs. Section 5.0 presents the visual variables that can be manipulated in presenting the individual elements of flowchart-format EOPs. Section 6.0 discusses the ways in which these individual elements can be assembled to create a flowchart. In Section 7.0, techniques for incorporating text into flowchart EOPs are presented, and Section 8.0 discusses the impact of changing from text EOPs to flowcharts on licensees' EOP programs.

Volume 2 presents a set of specific techniques for the preparation and implementation of flowchart EOPs. These techniques adhere to the general principles discussed in Volume 1 and describe a specific format for flowchart EOPs. To facilitate referencing from Volume 2 to Volume 1, the sections in Volume 2 are numbered as a continuation of the section number in Volume 1. Thus, Section 10.0 introduces Volume 2, and Section 11.0 summarizes Section 3.0. Section 12.0 presents flowchart layout techniques. Techniques for presenting the contents of EOPs in a flowchart can be found in Section 13.0. Section 14.0 presents techniques for including text in flowchart EOPs, while Section 15.0 provides techniques for emphasizing important information in flowchart EOPs. The implementation and maintenance of flowchart EOPs are discussed in Section 16.0, and Section 17.0 encourages experimentation with the techniques described in Volume 2.

2.0 PROJECT METHODOLOGY

This project involved several types of data gathering activities: (1) an extensive review of the literature regarding flowcharts, (2) reviews of actual flowchart EOPs, (3) interviews with consultants who produce flowchart EOPs for licensees, and (4) interviews with reactor operator licensing examiners regarding the technical aspects of flowchart EOPs. Detailed descriptions of these four activities are provided in this section.

2.1 SURVEY OF THE LITERATURE

Literature was surveyed from the fields of computer science, accounting, cartography, graphic design, technical writing, and psychology. The object of this search was to find information that pertains to flowcharts and to assimilate as much information as possible regarding the presentation of procedures in graphic forms. In addition to manual searches of libraries and journals, on-line searches of the Western Library Network, a database of regional libraries, and the National Technical Information Service were conducted.

Much of the literature specifically pertaining to flowcharts came from the computer industry, where flowcharts have been used for years as aids to programmers. This material was of limited applicability, however, because the computer industry uses flowcharts to diagram computer code, not as procedures to be followed. Only a few studies of flowchart procedures were found.

A number of standards for producing flowcharts were identified in the course of the literature search. These standards pertained to flowcharts in the computer industry, however, and provided little relevant guidance beyond giving the shapes of various flowchart symbols. Consequently, it was not possible to apply existing standards to flowcharting in the nuclear power industry.

To develop techniques for preparing flowchart EOPs, it was necessary to review basic principles of graphic design, technical writing, and human information processing. These principles formed the basis of the specific techniques presented in this report.

2.2 REVIEWS OF EXISTING FLOWCHART EOPs

Flowchart EOPs were collected from seven licensees representing both pressurized and boiling water reactors. These EOPs were used as reference materials to reveal the strengths and weaknesses of the flowcharts that are actually used in the nuclear power industry. The flowchart EOPs were of variable quality and usability. Many of the examples in this report come from, or are based upon, these flowcharts.

In addition to the reviews by the report authors, these flowcharts were shown to other staff at Battelle's Human Affairs Research Centers with experience in human factors, psychology, and engineering. Because these personnel had not worked as extensively with EOPs as the authors have, they brought a fresh perspective to the problem. Staff were asked to evaluate the flowcharts, using the evaluation checklist in Appendix A, but were encouraged not to confine their comments to the material covered on the checklist. Their comments are summarized in Appendix B.

2.3 INTERVIEWS WITH CONSULTANTS

Interviews were conducted with three firms that are involved in producing flowchart EOPs for licensees:

- On September 23, 1987, we met with human factors and training personnel from General Physics in San Diego, California.
- On November 19, 1987, we met with personnel from Operations Engineering, a consulting firm in Fremont, California.
- On November 20, 1987, we met with representatives from General Electric (GE) in San Jose, California. GE prepares flowchart EOPs for GE plants and is involved in the development of the Emergency Procedure Guidelines (EPGs), through the GE Boiling Water Reactor (BWR) Owners' Group. Because the majority of flowchart EOPs are used in GE plants, this interview was of particular interest.

In these interviews, problems associated with the design, production, and use of flowchart EOPs were discussed. The personnel with whom we spoke were helpful and spoke candidly with us about the advantages and disadvantages of the flowchart format. Appendix C contains the protocol used to guide the discussions.

2.4 INTERVIEWS WITH LICENSING EXAMINERS

To obtain an operations' perspective on flowchart EOPs, a meeting was held between project staff and several reactor operator licensing examiners at the Pacific Northwest Laboratory. Two of the examiners are licensed for GE plants; the other is licensed for Westinghouse and Combustion Engineering plants. In this meeting, we discussed the technical aspects of the various nuclear steam supply system (NSSS) owners' groups' guidelines, the differences between various flowchart formats, and any problems the examiners had observed involving the use of flowchart-format EOPs during licensing examinations.

3.0 FLOWCHART FORMATS

For the purposes of this report, a flowchart is defined as a diagram in which text and graphics are combined to present instructions for performing a task (i.e., a procedure). The text provides the instructions the user must follow and the decisions the user must make while performing the task. The graphics are symbols (e.g., boxes and lines with arrows) that serve to direct a user from one piece of text to the next and to communicate information about the type of actions needed to perform the task.

As a graphic form, flowcharts belong to a set containing networks and maps. Bertin (1981, 1983) distinguishes networks, flowcharts, and maps from other types of charts and graphs by the number of sets of information being displayed in the graphic representation. Many charts and graphs typically deal with two sets of information, one of which is plotted along the x axis of the chart and the other of which is plotted along the y axis. By contrast, networks, maps, and flowcharts focus on showing the interrelationships within a single set of information. Winn and Holiday (1982) also note this distinction, but they stress that flowcharts and diagrams are more similar than they are different.

Blaiwes (1973) and Twyman (1980) also note that maps, flowcharts, and tree-structured data presentations, such as organizational charts, have characteristics in common. In some cases, maps and flowcharts look quite similar. Consider, for example, Figure 3.1, which is a map (or a flow diagram) of a bus route. In this map, and other maps of this genre, the precise location of items is not important, although certain prominent landmarks, such as bodies of water, are shown and may be useful to users. Additionally, a great deal of unimportant detail is omitted. What is important to the user is the relative positions of locations along the bus routes (i.e., the flowlines). This map is designed to show how one can move (flow) from one location to another, rather than to show precisely where places are physically located. Maps like that shown in Figure 3.1 are graphically similar to flowcharts.

Examination of flowchart EOPs and a review of the relevant literature revealed that the term "flowchart" encompasses a variety of structures that the share the characteristics described above; see Figure 3.2. These structures, which differ both in function (i.e., the needs they are intended to serve) and in format (i.e., how they appear), can be divided into two functional groups: (1) flowcharts that are written as algorithmic decision aids and (2) diagrams that use flowcharting techniques to present instructions for performing two or more tasks concurrently. The first type of flowchart is referred to in this report as an algorithmic flowchart and is discussed in Section 3.1; the second type is referred to as a "big-picture" flowchart and is discussed in Section 3.2. The primary disadvantage of both types of flowcharts--the limit on the level of technical detail that can be presented--is discussed in Section 3.3.

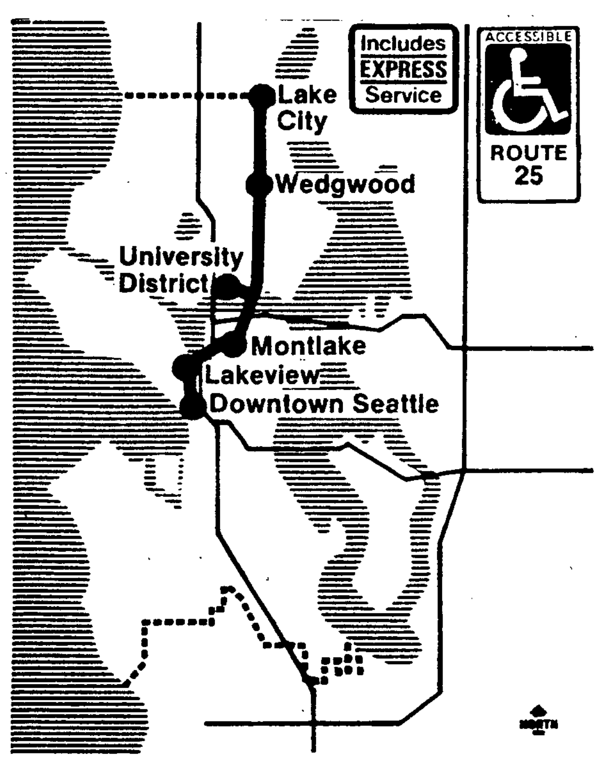

FIGURE 3.1. Flow Diagram of a Bus Route

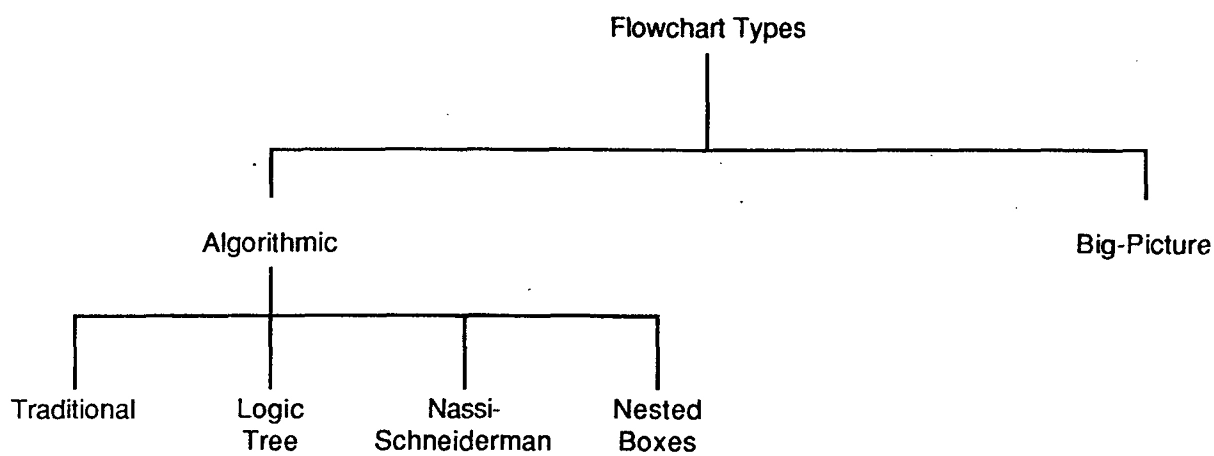

FIGURE 3.2. Types of Flowcharts

3.1 ALGORITHMIC FLOWCHARTS

The advantage of algorithmic flowcharts is that they allow complex instructions to be presented in a simple, sequential manner. There are some serious limitations to the use of algorithmic flowcharts for presenting EOPs, however. In this section, four formats for presenting algorithmic flowcharts are described, and the advantages and disadvantages of using algorithmic flowcharts for presenting EOPs are discussed.

3.1.1 Algorithmic Flowchart Formats

Four types of algorithmic flowcharts have been described in the literature, although only two of these (the traditional and logic tree formats) are currently used in the nuclear power industry for EOPs. The four types of algorithmic flowcharts are traditional flowcharts, logic trees, Nassi-Schneiderman flowcharts, and nested-boxes flowcharts.

3.1.1.1 Traditional Flowcharts

The traditional flowchart uses symbols of various shapes as boxes that enclose small bodies of text. An example of a traditional flowchart is shown in Figure 3.3. A symbol of a given shape conveys a given meaning. In its simplest form a flowchart contains three components: decision boxes, flowpaths, and action boxes (Krohn, 1983). Decision steps are typically represented by diamond-shaped boxes, while action steps are indicated by rectangles. The sequence of steps is indicated by flowlines with arrows. A user of a traditional flowchart moves from one symbol to the next as directed by the flowlines. At decision points, a flowpath branches into two or more flowpaths, and the user must select one of these paths. The decision criteria necessary to make this selection are placed within the decision symbol in the form of a question. Ovals, circles, or rectangles with rounded corners mark the entry and exit points.

Twyman (1980) uses the term "linear branching" to describe the traditional flowchart format. The flow of information from action symbol to action symbol is linear, but branches at decision points, where a single path separates into two or more paths. However, the term linear branching is an incomplete description of the traditional flowchart structure, because the flow of movement may include the merging of flowpaths.

3.1.1.2 Logic Trees

Logic trees are very similar to traditional flowcharts. The key difference between the two formats is that logic trees have a true linear branching structure; flowpaths do not merge in logic trees. An example of a logic tree is shown in Figure 3.4. Logic trees generally use the same symbols as traditional flowcharts. Movement through the flowchart is directed with flowlines, and decision criteria at flowline branching points (i.e., decision symbols) are given in a question format.

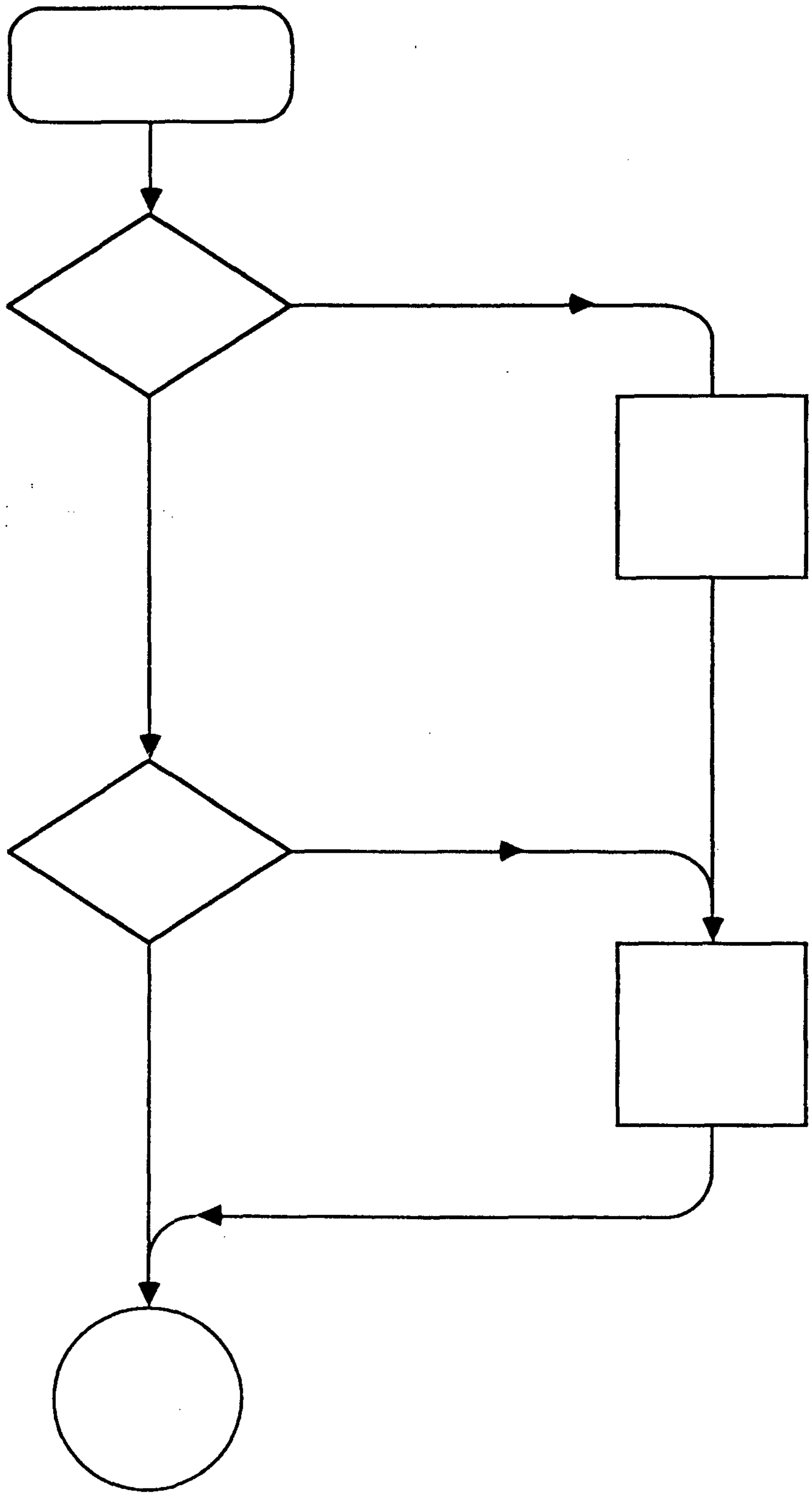

FIGURE 3.3. Traditional Flowchart

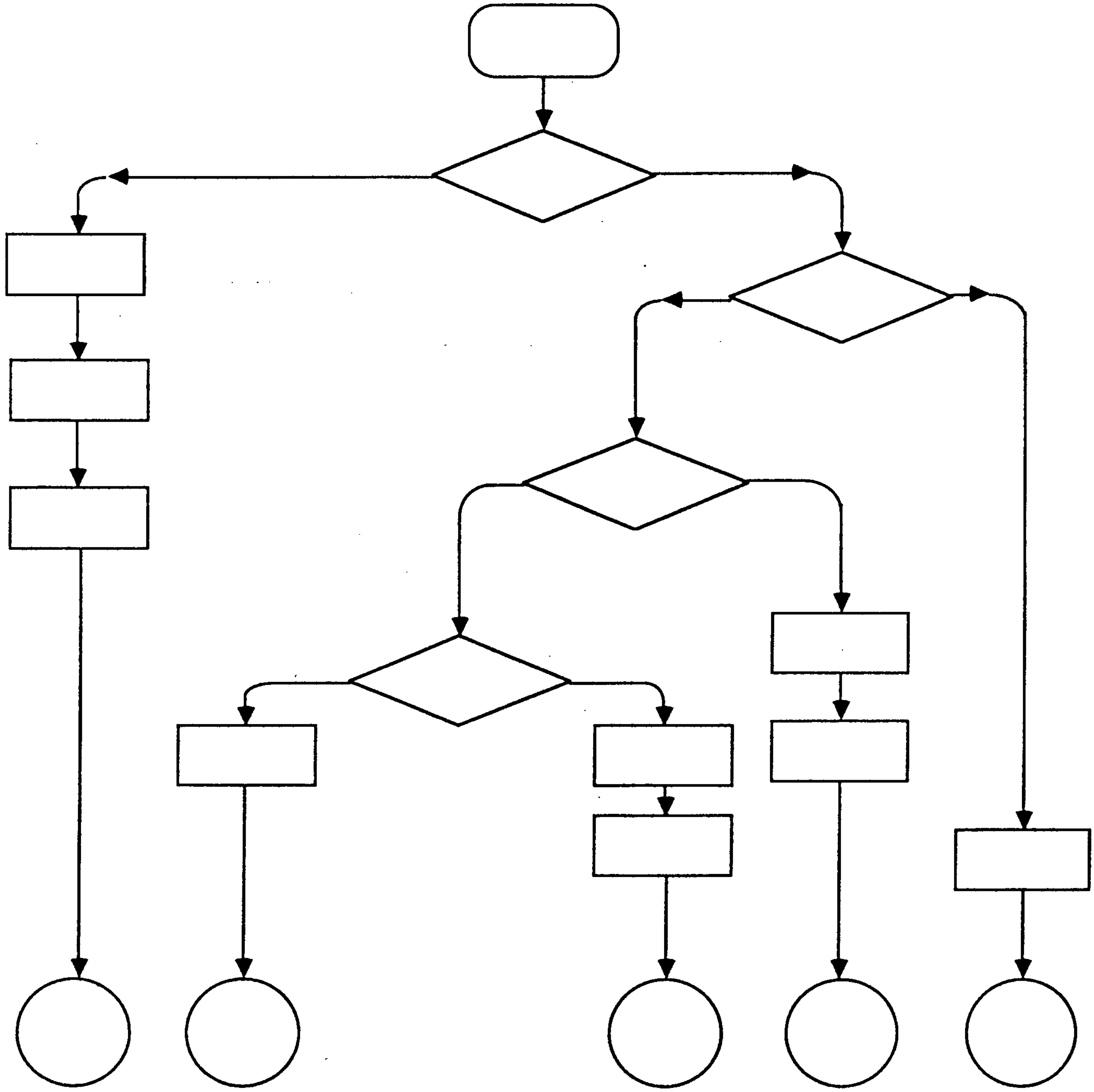

FIGURE 3.4. Logic Tree

Because their flowpaths do not merge, logic trees cannot present lateral movement from one flowpath to another or loops and bypasses that direct the user to repeat or skip one or more steps in certain circumstances. Logic trees also increase in size as movement through them progresses, making them too unwieldy for complex procedures. Consequently, logic trees are usually used for simpler, shorter procedures, such as diagnostic procedures when a user will take only one of many possible actions and must make several decisions to reach that action.

3.1.1.3 Nassi-Schneiderman Flowcharts

The Nassi-Schneiderman flowchart shows the types of hierarchical relationships that are usually lost in traditional flowcharts and logic trees (Agarwal, 1984). The most striking feature of Nassi-Schneiderman flowcharts is that they do not contain flowlines (with the exception of a single short flowline connecting the entry symbol to the rest of the flowchart). An example of a Nassi-Schneiderman flowchart is shown in Figure 3.5. The Nassi-Schneiderman flowchart uses four symbols: (1) an oval entry point, as at the top center of Figure 3.5; (2) rectangles for general information and action steps, as in Step 1 in Figure 3.5; (3) rectangles with triangles embedded in the lower corners, as in Step 3 in Figure 3.5; and (4) shaded steps, as in Step 2 in Figure 3.5. One moves through the flowchart vertically, moving straight down when leaving the entry symbol, a rectangular symbol, or a shaded symbol. The information within the shaded symbol remains applicable throughout the steps bracketed by the vertical leg of the symbol. For example, in Figure 3.5, Step 2 applies to Steps 3 through 13 and Step 5 applies to Steps 6 through 13. The steps with the embedded triangles are decision points, and one can move either down to the left or to the right from one of these steps. For example, in Figure 3.5, Step 3 is a decision point. If the ABC mode gates were secured prior to natural circulation, the operator goes to the next page; if the mode gates were not secured, the operator goes to Step 5 and performs the remaining steps in the flowchart.

The strength of this style of flowchart is that it can show some types of relationships more clearly than can a traditional flowchart. Some of the types of information that are clearly displayed in this flowchart are as follows:

- Steps of continuous applicability (e.g., Step 2 is applicable through Step 13).
- The hierarchy of decisions and consequent actions or contingency actions (e.g., Step 7 is an action to be performed if the decision reached at Step 6 is yes; Steps 8 through 12 are contingency actions that are followed if the answer to Step 6 is no.

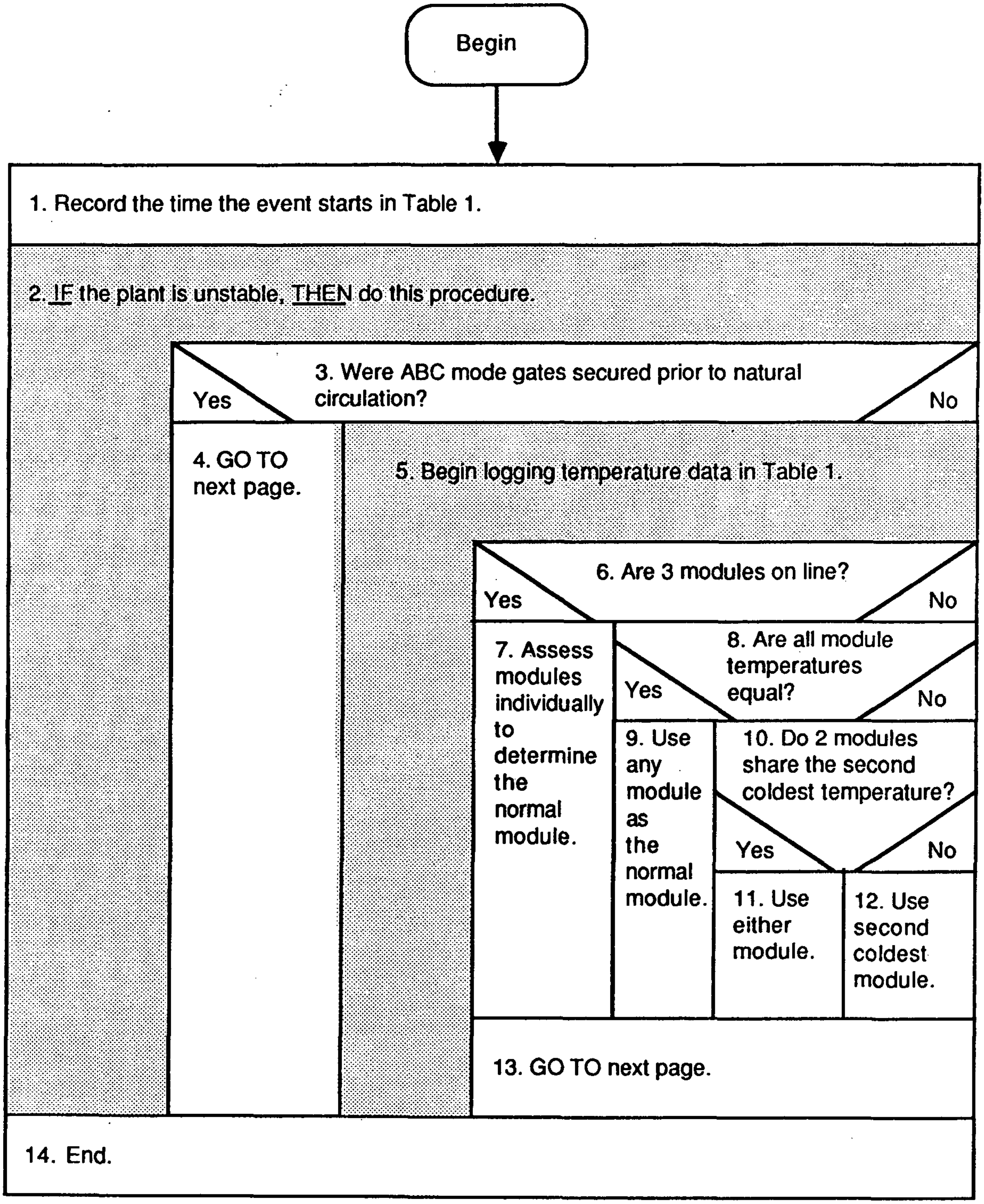

FIGURE 3.5. Nassi-Schneiderman Flowchart

The structure of the flowchart also simplifies placing page or column breaks within a long flowchart. For example, a logical page break occurs following Step 14. However, breaks could not be placed between Steps 2 and 13 without destroying the graphics of the flowchart. It is conceivable that a long procedure could be formatted as a series of Nassi-Schneiderman "modules," with each module representing a logical unit of information. Because the graphics of the flowchart are determined by the logic of the information, page breaks that are of minimal graphic disruption would also be of minimal logical disruption.

There are aspects of the Nassi-Schneiderman flowchart that make it ill-suited for EOPs, however. Lindsey (1977) notes that an inherent weakness of the Nassi-Schneiderman flowchart is that it does not provide a means of formatting the occasional jump needed in structured computer programming. Because referencing and branching (i.e., jumping from one part of a procedure to another part of the same or a different procedure) are integral parts of EOPs, the type of flowchart used to present EOPs must allow for referencing and branching. Additionally, because the information in the Nassi-Schneiderman flowchart is densely packed, it would be difficult to incorporate a placekeeping method into the flowchart. Finally, Nassi-Schneiderman flowcharts are visually very busy. If all of the additional coding required in flowchart EOPs were added to such a flowchart (e.g., graphics to show cautions, notes, and special types of steps), it would create a confusing visual image.

Because of its inherent limitations, it appears that the Nassi-Schneiderman flowchart is not a suitable format for presenting EOPs. The inability of this type of flowchart to show referencing and branching, its inability to accommodate many additional graphic cues for specific EOP concerns, and its inability to accommodate placekeeping are particularly problematic. However, the technique of having some steps bracket others may be useful in flowchart EOPs to indicate step groupings.

3.1.1.4 Nested-Boxes Flowcharts

Lindsey (1977) proposes a flowcharting technique based on nested boxes. This flowchart provides stronger hierarchical cues than the Nassi-Schneiderman flowchart. An example of such a flowchart is shown in Figure 3.6. By showing relationships of items as nested sets, this representation graphically shows some types of relationships among the flowchart elements more clearly than does a traditional flowchart or a logic tree.

However, the hierarchical cues provided by the nested-boxes format can create difficulties in presenting an EOP. Boxes can either be nested inside other boxes, stacked on top of other boxes, or both. Nested boxes and stacked

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[1]Page breaks are generally more disruptive in flowcharts than in text procedures. In text procedures, readers move from the bottom of one page to the top of the next. In flowcharts, on the other hand, readers frequently must locate an entry point in the midst of the flowchart.

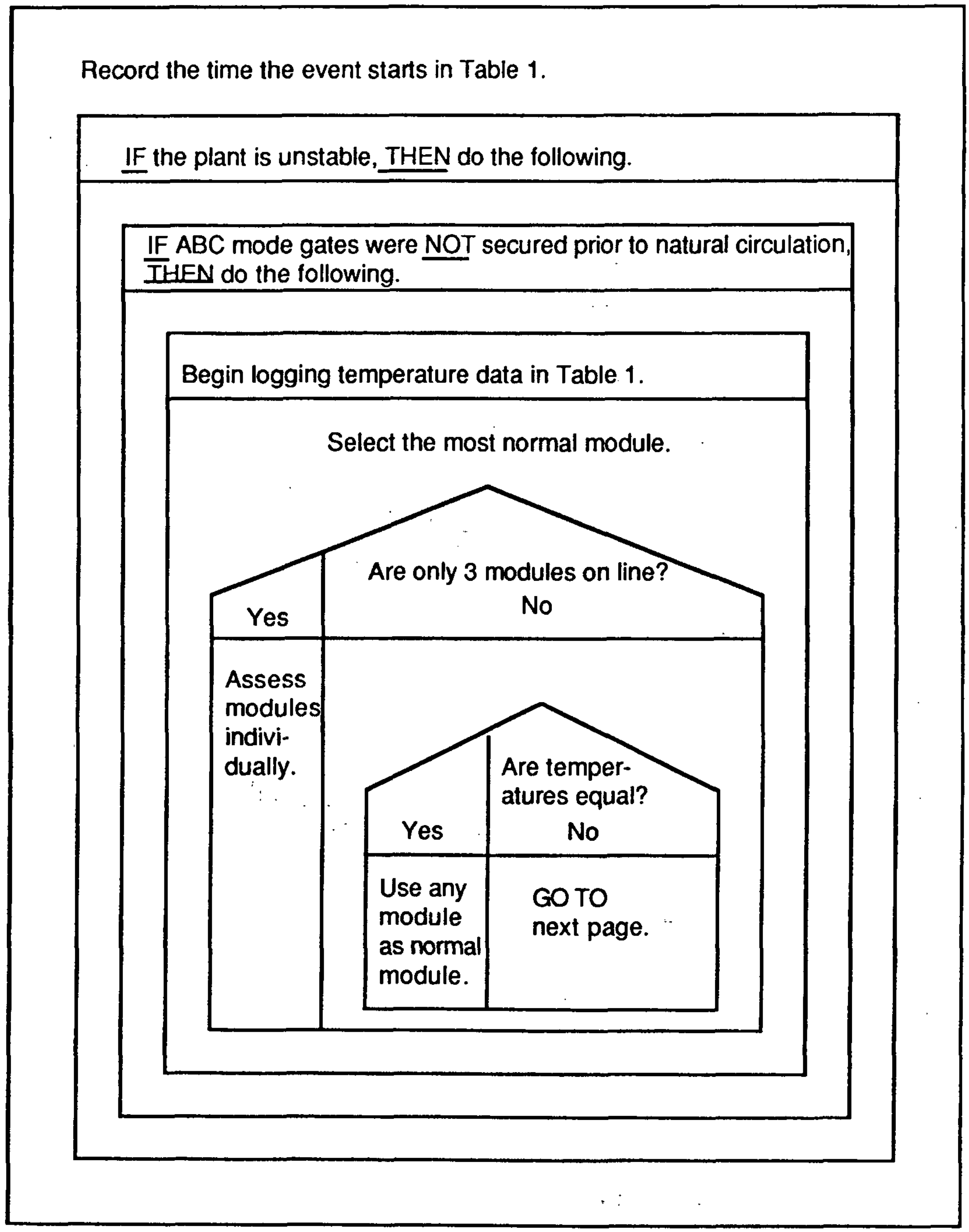

FIGURE 3.6. Nested-Boxes Flowchart

boxes present two entirely different types of information: nested boxes are substeps, while stacked boxes are a series of steps. Because it can be difficult to tell nested boxes from stacked boxes, and thus substeps (which provide detail) from sequential steps, nested-boxes flowcharts can present placekeeping problems. The text procedure in Figure 3.7 is presented in the nested-boxes format in Figure 3.8 to illustrate this problem; note how difficult it would be for an operator to keep his place in Figure 3.8, as compared to Figure 3.7.

Nested-boxes flowcharts also consume a great deal of space. Compare the space used by Figure 3.7 versus that used by Figure 3.8. If another level of detail were added to Figure 3.8, every box in the diagram would have to be enlarged so that the nesting relationship could be maintained. If another level of detail were added to the text procedure in Figure 3.7, the procedure would merely become a few lines longer.

Further, the large empty space in the "IF EFW is available..." step in Figure 3.8 wastes space and may provide the false cue that this step is more important than any other step in the procedure. As is explained in Section 5.3.5 of this report, in any graphic representation, smaller objects will appear less important than larger objects. If one is graphing a hierarchy of items, this property of size variation may accurately reflect the logical relationships of the items graphed. However, if one is graphing a sequence of equally important procedural steps, this property of size may distort the relative importance of the steps.

Another problem with formatting EOPs as nested boxes is that, as the boxes change in shape and size, it is very difficult to maintain a visible, consistent format for information of equal importance. Furthermore, with the procedure text presented in small, compact boxes, there is little space left for operators to add placekeeping marks or notations.

A final problem with the nested-boxes flowchart is the closely spaced parallel lines, which can cause disturbing moire' vibrations, as explained in Section 5.3.8 of this report. The notion of nesting steps within others may be of some benefit in flowchart EOPs, especially for showing items such as entry conditions, override steps,[2] or cautions that apply to a series of steps. However, this style of flowchart is too limited to be a useful format for presenting EOPs.

3.1.1.5 Types of Algorithmic Flowcharts Used in the Nuclear Power Industry

Only two of the four algorithmic flowchart formats are used in the U.S. nuclear power industry, to the best of our knowledge. Algorithmic flowcharts

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[2]Override steps are steps that apply to several other steps. If a specified condition exists, the override step takes precedence over the other steps and is performed instead. Override steps are best drawn to bracket the steps to which they pertain, so that it is easy to see exactly which override steps apply at any point in the procedure.

3.1 CONCURRENTLY PERFORM VP-580, Plant Safety Verification Procedure, and begin with Step 1.0

3.2 Notify SOTA of upset.

3.3 Verify required OTSG level setpoint is selected from Table 1.

3.4 IF EFW is NOT available,
THEN maintain feedwater flow to OTSGs.

3.4.1 IF the Feedwater Pump is NOT running,
THEN start it.

3.4.2 Ensure Start-Up Block Valves are open.

- FWV-33
- FWV-36

3.4.3 Throttle Start-Up Control Valves.

- FWV-33
- FWV-36

FIGURE 3.7. Text Procedure

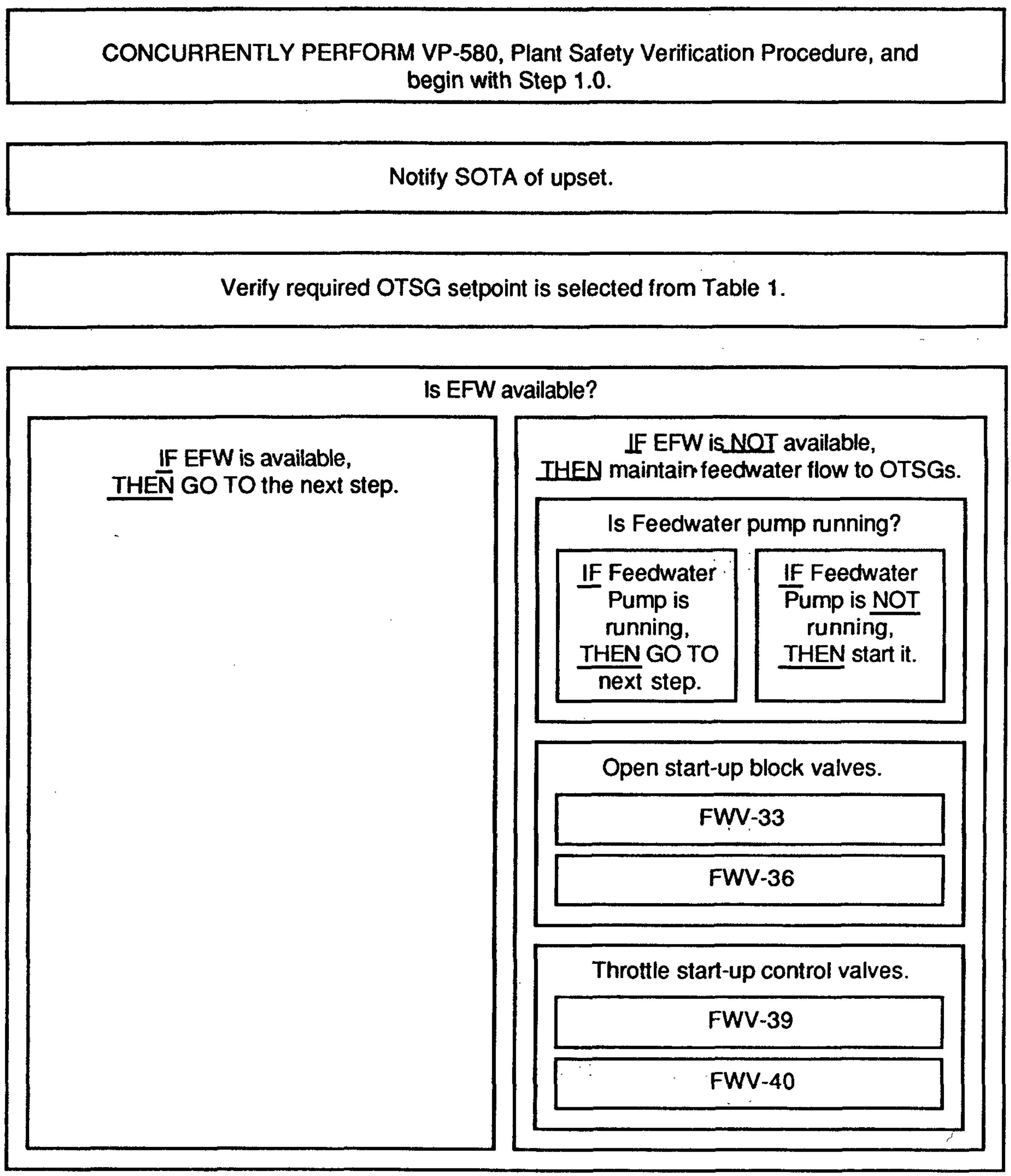

FIGURE 3.8. Nested-Boxes Flowchart of the Text Procedure in Figure 3.7

in the traditional format are used primarily in pressurized water reactors (PWRs) where they serve as diagnostic procedures that branch the operators into the correct text procedure once the emergency event has been identified and the appropriate immediate actions taken. Critical Safety Function Status Trees (CSFSTs), which are logic trees, are used at most, if not all, Westinghouse plants. Operators use CSFSTs to continually monitor certain crucial plant parameters once an EOP has been entered. If a parameter reaches a degraded or critical level, the CSFST instructs the operator to perform the appropriate procedure to restore the status of the parameter. Nassi-Schneiderman flowcharts and nested boxes are not currently used in the U.S. nuclear power industry.

For the remainder of this report, the term "algorithmic flowchart" refers to a traditional flowchart or a logic tree. Because of the similarities between the two formats, it is normally unnecessary to distinguish between traditional flowcharts and logic trees; however, the distinction will be made where it is important.

3.1.2 Advantages of Algorithmic Flowcharts

The primary advantage of algorithmic flowcharts, compared to text procedures, is that they allow complex decisions to be presented more clearly. The linear branching structure of an algorithmic flowchart provides a smooth flow of information to operators and can reduce the burden on short-term memory imposed by decisions presented as logic statements[3] in text procedures.

The smoother flow of information in algorithmic flowcharts compared to text procedures is a function of the manner in which decisions are treated in the two formats. In text EOPs, decisions are typically presented as logic statements which require non-linear movement through the text. For example, if a step in an EOP contains an IF...THEN statement, operators will only perform the consequent (the clause following THEN) if the antecedent (the clause following IF) is true. If the antecedent is false, operators make a non-linear movement in the EOP as they skip the consequent. In an algorithmic flowchart, operators do not skip over steps. As can be seen in Figure 3.9, the operator follows a single flowpath out of a decision symbol when making a decision, and so is not required skip over any information. More complex decision points in text procedures, particularly those involving

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[3]Logic statements in EOPs can be complex and are thus presented in a rigid format using logic terms such as IF, WHEN, AND, OR, and THEN to avoid their being misunderstood. These terms are generally capitalized and underlined. The antecedent (the condition) always precedes the consequent (the action). The antecedent always begins with an IF or a WHEN, and the consequent is always introduced with a THEN. Multiple conditions or actions are joined with AND or OR, as appropriate. An example of a correct logic statement would be "IF the reactor trips, THEN trip the turbine." An example of an incorrect logic statement would be "Trip the turbine IF the reactor trips." See Appendix B of NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982), for a more complete discussion.

IF Reactor has tripped,
THEN trip the turbine.

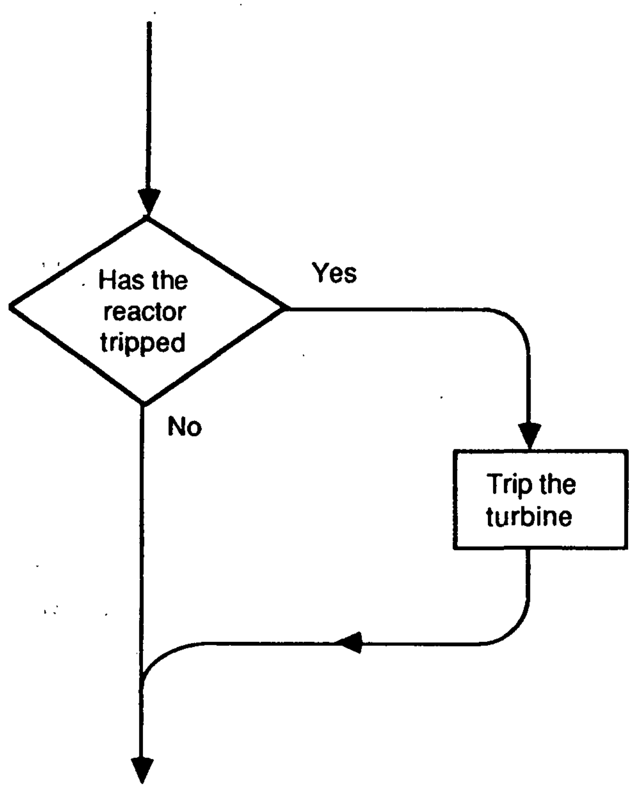


FIGURE 3.9. Simple Logic Statement and the Corresponding Portion of a Flowchart

referencing or branching, may require operators to skip an entire sequence of steps, whereas algorithmic flowcharts allow the operator to move through complex decisions without interruptions. This format for presenting non-linear instructions can make EOPs that contain many decision points easier to follow.

Another advantage of a linear branching structure is that operators do not have to remember previous decisions as they progress through the flowchart (Wason, 1968), because flowcharts break a problem into a series of simple decisions and operators make these decisions one at a time. In text procedures, operators are often required to remember previous decisions. For example, assume a step in a text procedure states, "IF RCPs are available AND adequate subcooling margin is restored, THEN start 1 RCP in each loop." When an operator performs this step, he must check if RCPs (reactor coolant pumps) are available. Then he must check the subcooling margin and, remembering the RCP status, decide whether or not to start an RCP. Granted, this example places a minimal demand on short-term memory, but in a stressful situation, such as might be encountered during an emergency event, the operator could incorrectly remember the RCP status and make a mistake.

A flowchart, on the other hand, would break this step into two decision points, as shown in Figure 3.10. The first decision would concern the RCP status: if RCPs were available, operators would follow the flowpath out of the decision symbol that led to the second decision point asking whether subcooling was adequate; if subcooling was not adequate, operators would follow a path that returned to the original flowpath. If subcooling was adequate, operators would follow the flowpath that led to the instruction to start 1 RCP in each loop. Thus, when operators encountered the decision about subcooling, they would not have to remember the previous decision about RCP status, because, if RCPs were not available, they never would have encountered the decision about subcooling.

Because they can simplify decision making in EOPs, algorithmic flowcharts are likely to be of greatest value when presenting procedures that contain many decisions. A number of studies have demonstrated the superiority of flowcharts over text for presenting such procedures:

- Wright (1971) stated that "the logic tree would seem to be particularly appropriate for 'trouble shooting' problems, where from the very nature of the task it is unlikely that the cause of the trouble is known from the onset. Even when the number of possible faults is known to the operator, the logic tree helps the man to check through each of the possibilities without there being any risk of forgetting some" (p. 208).

- Kammann (1975) used flowcharts for presenting telephone dialing procedures, which consist primarily of decisions, and found that the "flowchart format can produce a higher level of direct comprehension than is obtained with a standard prose format" (p. 190).

IF RCPs are available
AND adequate subcooling margin is restored,
THEN start 1 RCP in each loop.

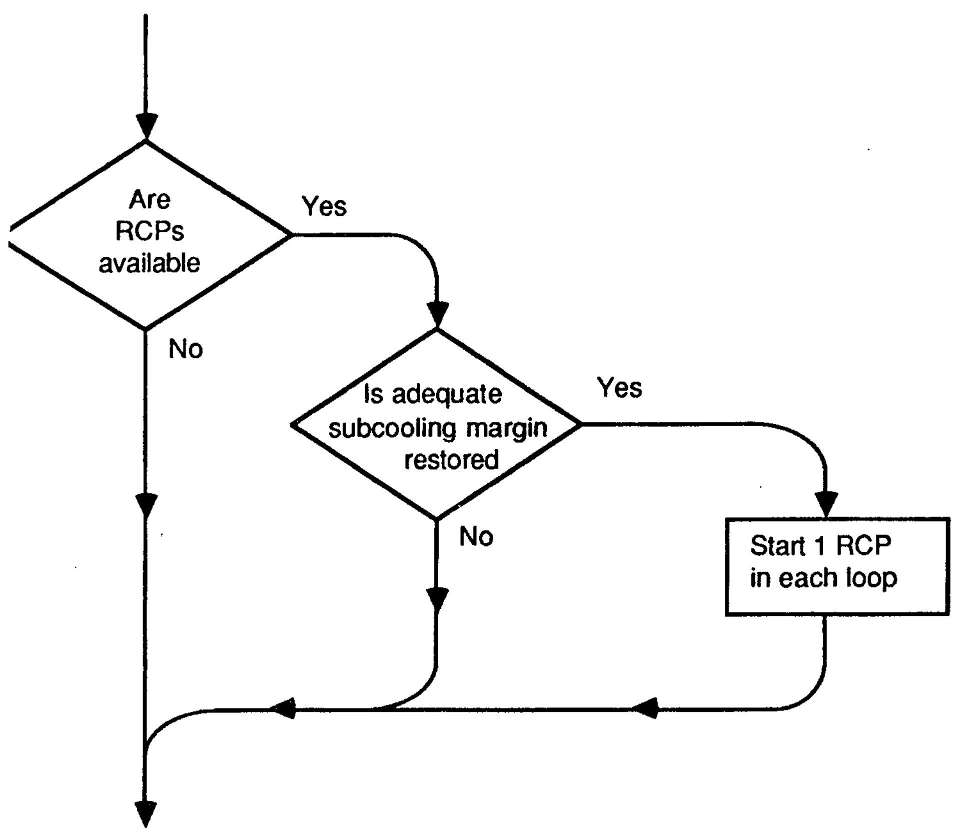


FIGURE 3.10. Complex Logic Statement and the Corresponding Portion of a Flowchart

- In a study in which the procedures for making a medical diagnosis from an X-ray were written as flowcharts and used in the classroom, Tuddenham (1968) concluded that the flowcharts were superior to other procedure formats.

- Aspinall (1976) suggested that logic trees might be useful in helping nurses to diagnose diseases. She noted that nurses often diagnosed diseases by recalling a memorized list of symptoms; the presence of all these symptoms indicated the patient had a certain disease. However, the nurses often could remember only a few of the symptoms, and would incorrectly diagnose a disease when they observed only those symptoms that they remembered. If they had remembered the complete list, they would see that other symptoms were not present and that their diagnosis was incorrect. In Aspinall's study, "significant improvement in diagnostic accuracy was shown by the nurses who used the decision trees" (p. 182).

- Mallamand, Levine, and Fleishman (1980) experimented with two methods for ranking the abilities required to perform a job: a variable scale, and a flowchart consisting of 40 binary decisions. They found that the flowchart was a superior means of rating the abilities.

- Merrill (1980) defined complex procedures as those that "contain several decision points and many operations. The multiple decision points lead to several alternate paths through the procedure.... The most appropriate presentation for complex procedures would be flowcharts or decision tables" (p. 21).

3.1.3 Disadvantages of Algorithmic Flowcharts

There are three major disadvantages to the use of algorithmic flowcharts for presenting EOPs: (1) algorithmic flowcharts are not the best format for presenting lists of action steps; (2) emergency events in a nuclear power plant can be so complicated that mitigation does not lend itself to a rigid algorithmic analysis; and (3) algorithmic flowcharts divide processes into such simple steps that the relationships between these steps are not evident.

3.1.3.1 Algorithmic Flowcharts That Consist Primarily of Action Steps

The value of algorithmic flowcharts decreases as the complexity of the procedure (that is, the number of decision points) decreases, because the very graphic devices that simplify non-linear procedures become unnecessary and cumbersome in linear procedures. A list of instructions presented as a flowchart would consist merely of a series of boxes containing action steps connected by lines. Such a simple flowchart would be larger than a corresponding text procedure (because graphics occupy space) and unnecessarily more complex (because the graphics would not provide useful information). Thus, algorithmic flowcharts are inferior to text procedures when few decisions are required (Merrill, 1980, 1982).

3.1.3.2 Order of Steps Imposed by an Algorithmic Flowchart

A second limitation of algorithmic flowcharts is that steps in an EOP that are not performed in a strict sequential order are difficult to present. For example, a flowchart that includes override steps or steps that are to be performed at an indefinite time (which would be dictated by plant parameters) would either have to repeat these steps and any appropriate decision criteria that operators would need when deciding to perform them throughout the procedure, or would have to resort to a non-standard graphic device, such as bracketing a series of steps. The first alternative, repeating the steps, would make the flowchart long and cumbersome; the second alternative, a graphic device of some sort, might make a flowchart that was already graphically complex more difficult to follow.

Problems can arise even when there is an apparent "correct" order for the steps in a procedure. Refer to the flowchart example in Figure 3.11. When moving along the flowpath, an operator will first encounter the decision regarding the subcooling margin. Assume that adequate subcooling has not been restored. The operator will exit that step at the "no" branch and will never encounter the question about the availability of the RCPs. Assume that subcooling then becomes adequate. Both conditions are now true, but the operator will not start an RCP in each loop because the subcooling margin was not adequate at the time the operator encountered the first decision diamond. An experienced operator would monitor the subcooling margin and would not be likely to make such an error; but this operator would be relying on his or her own knowledge to overcome an inadequacy in the procedure. The fact remains that the linear branching structure of an algorithmic flowchart imposes a rigid sequence on the steps in the flowchart. The antecedents to starting one RCP in each loop appear in separate symbols and are connected by arrows, which are very powerful graphic cues to indicate that something precedes something else. If the conditions in the plant do not occur in the same sequence in "real time," the procedure, followed verbatim, will lead to incorrect actions.

Text procedures do not imply such a rigid sequence of steps. A written version of this step, "IF adequate subcooling margin is restored AND RCPs are available, THEN start 1 RCP in each loop," does not imply as rigid an order for considering the two antecedents as does the flowchart. One of the antecedents appears before the other, of course, but the two antecedents appear as equals because of the linking AND. The issue is one of grouping: because the antecedents in a text procedure are grouped together, operators can vary the order in which the antecedents are considered without affecting the order in which the steps are performed.

Grouping could be used in an algorithmic flowchart, by enclosing the antecedent of the logic term ("IF adequate subcooling margin is restored AND RCPs are available") in a decision symbol, but then an operator confronted with this step might be more likely to make an error than an operator confronted with the version presented in Figure 3.11, because the decision is no longer broken into its simplest components. The likelihood of error would increase as the number of conditions in the antecedent increased or if the conditions were joined by combinations of AND and OR.

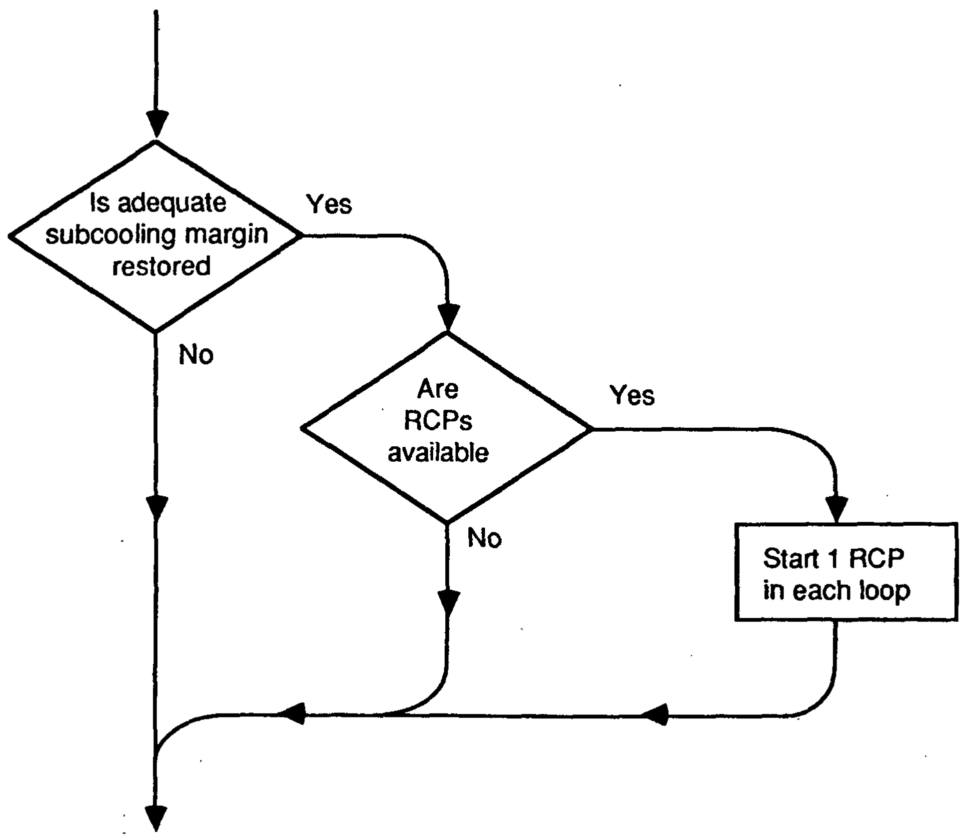


FIGURE 3.11. Lack of Grouping in an Algorithmic Flowchart

The more complex the antecedent, the greater the advantage the flowchart version of the step will have in reducing errors in decision making. However, the flowchart version, which presents information in a sequential and ungrouped manner, will impose an order on these conditions that is stronger than the order imposed by the logic statement.

3.1.3.3 Grouping in an Algorithmic Flowchart

The lack of grouping in an algorithmic flowchart leads to another problem. In the flowchart shown in Figure 3.11, an operator sees three distinct elements with no relation between them. A newly certified operator might believe, in Figure 3.11, that he was starting an RCP only because an RCP was available, as that was the decision that led him to the instruction to start the RCP. An experienced operator would realize that he is starting an RCP because an RCP was available <u>and</u> because subcooling was adequate, but only as a result of his or her greater knowledge. The connection is not evident from the flowchart. A logic statement, on the other hand, clearly indicates why the operator is starting the RCPs. This problem of context would be worse in a full-sized flowchart, where these steps would not be seen in isolation, as they are here, but would be embedded in a complex series of steps; see, for example, Figure 3.13, page 3-27.

Algorithmic flowcharts break procedures into a simple sequence of steps, allowing users to make simple decisions one at a time. In so breaking down a procedure, however, the relationships between these simple decisions are lost. These relationships provide important information to operators, because they often indicate <u>why</u> something is being done: in the example in Figure 3.11, the operator is checking subcooling to determine if he should start an RCP. If an operator is not aware of why he is performing a step, he cannot question what he is doing, and an important check on the correctness of the procedure or the operator's actions, or both, is lost.

3.1.4 <u>Summary</u>

Any theoretical advantages of an algorithmic flowchart as a decision aid must be considered in relation to the disadvantages imposed by the flowchart format in the "real world": flowcharts written as algorithms are large, graphically complex, do not provide much of the organizational and hierarchial information provided by text procedures, and may be too precise to conform to the sequence of events that will occur during an emergency. Further, algorithmic flowcharts are an inferior format for presenting procedures that do not contain many decisions. There is, however, some evidence that algorithmic flowcharts reduce errors in decision making. The algorithmic flowchart designer is thus faced with a paradox: algorithmic flowcharts, if correct, reduce errors in decision making but may introduce errors of other types. Furthermore, because steps are not grouped and operators are less aware of why they are performing actions, there is a greater chance that an error in performing the procedure will not be caught by the operators.

Because algorithmic flowcharts can be beneficial as decision aids, licensees should consider presenting EOPs that contain many decisions as algorithmic flowcharts. EOPS that contain few decisions and many actions would probably be best presented in text format.

3.2 BIG-PICTURE FLOWCHARTS

Big-picture flowcharts were developed to meet specific needs within the U.S. nuclear power industry. Although they are called flowcharts, big-picture flowcharts differ substantially from algorithmic flowcharts in that their primary purpose is not to simplify decision making; rather, big-picture flowcharts are intended to present the concurrent actions (as required by the EOPs used in General Electric [GE] plants). Big-picture flowcharts are a hybrid of text and flowcharts, and are often closer to text.

3.2.1 Development of Big-Picture Flowcharts

Flowchart designers interviewed as part of this study indicated that, after the TMI incident, the different NSSS owners' groups independently developed generic technical guidelines, with each owners' group developing a different philosophy towards EOPs. The GE Boiling Water Reactor (BWR) Owners' Group developed an approach that required procedures to be executed concurrently. These procedures were first written as text procedures; however, operators found it difficult to concurrently use text procedures bound in notebooks, because they were required to be on several pages at once. Vendor and utility human factors personnel felt that this situation could be improved by presenting EOPs in a graphic format. Consequently, the GE BWR Owners' Group Emergency Procedure Guidelines (EPGs), Revision 4, which are text guidelines, were written to facilitate conversion to the flowchart format, although licensees are free to develop EOPs in whatever format they choose.

3.2.2 Format of Big-Picture Flowcharts

The "big picture" referred to in the term "big-picture flowchart" is an overview of the situation in the plant as a whole. The flowcharts take the form of flowpaths side by side on a large sheet of paper. Each of these flowpaths is a separate procedure and, as required by the nature of the emergency event, several paths may be performed concurrently. An example of the big-picture format is shown in Figure 3.12.

Big-picture flowcharts are comprised of many of the same symbols used in traditional flowcharts; big-picture flowcharts consist primarily of rectangular action steps and a few diamond-shaped decision symbols. However, a variety of non-traditional graphic devices are also used in big-picture flowcharts to provide operators with additional information. These include override steps and decision tables.

The key to a big-picture flowchart is a simple graphic presentation. The graphic structure of a big-picture flowchart is simplified in three ways:

- Multiple decision criteria are frequently combined in a single decision symbol, using logic statements that reduce the number of separate symbols required in the flowchart.

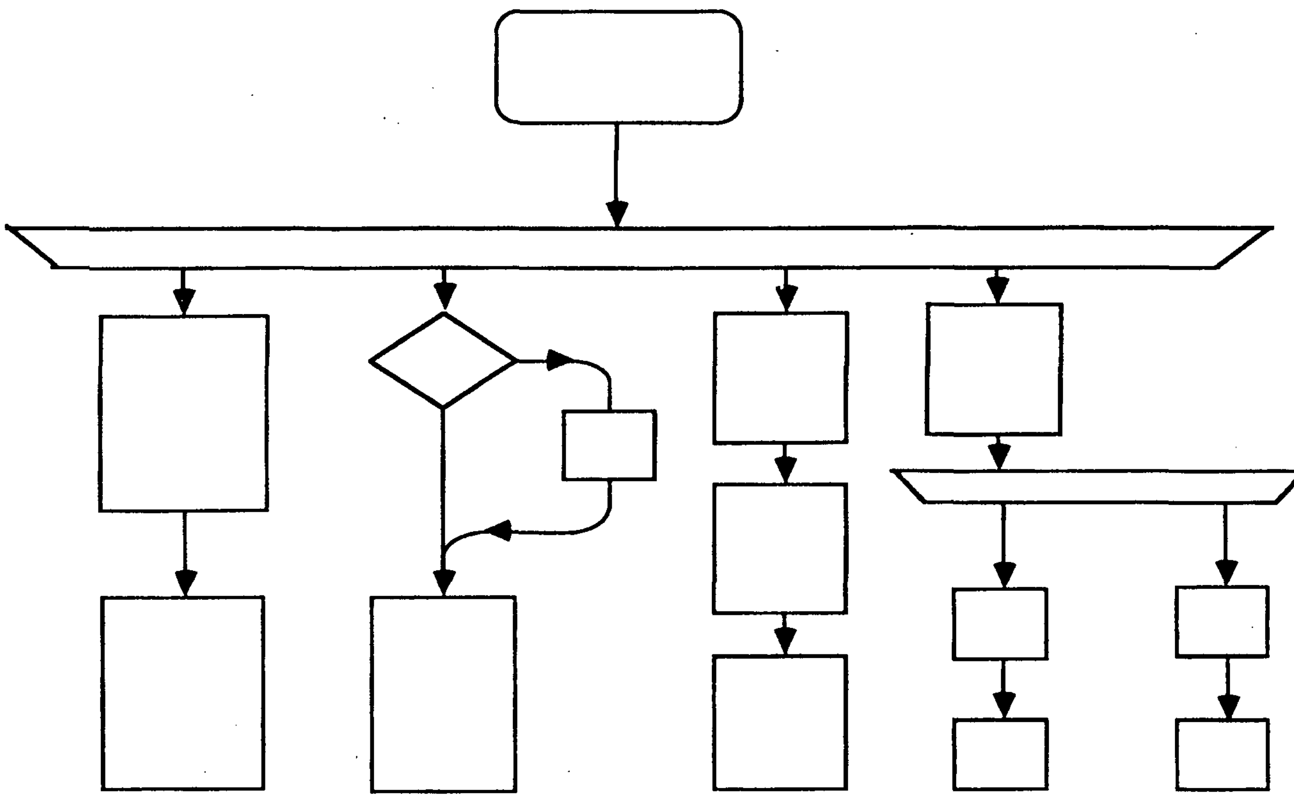


FIGURE 3.12. Big-Picture Flowchart Format

- Big-picture flowcharts often use simplified flowpaths that do not include exits. Each successive step is performed if the previous step does not restore a particular parameter to a safe and stable condition. Operators simply stop performing the steps in the path when the situation has returned to normal. Many of the decisions that must be explicitly shown in algorithmic flowcharts are implied in the big-picture format.

- The level of technical detail in the flowcharts is limited which reduces the amount of information that must be presented.

The graphic simplicity of a big-picture flowchart has several advantages. In a properly drawn big-picture flowchart, operators can look ahead and see where they are going, and see what portion of the procedure still needs to be performed. Operators can also move between columns without losing their place. Further, the operator can look back for override steps that may still be applicable. Operators can also review the procedure for relevant cautions, which can be formatted so that they are readily apparent. Because the flow of movement through the flowchart is indicated with flowlines, operators also can easily see any referencing and branching between flowpaths.

3.2.3 Limitations of Big-Picture Flowcharts

There are two major limitations to big-picture flowcharts. The first limitation is the difficulty operators may experience when required to perform more than one or two procedures concurrently. The second limitation is that big-picture flowcharts typically do not provide any better decision support than text procedures.

The primary disadvantage of big-picture flowcharts is that operators may be required to monitor up to eight flowpaths simultaneously on different flowchart sheets. It is likely to be difficult for an operator in the dynamic and stressful environment present in the control room during an emergency event to be aware of and effectively establish priorities between several concurrent tasks, as required by the GE BWR Owner's Group philosophy behind the EPGs. The cognitive demand placed on operators who are following several flowpaths concurrently is further increased by the requirement to monitor progress on flowpaths that are located on different flowchart pages.

Yet big-picture flowcharts appear to work. Operators establish priorities between flowpaths by monitoring critical plant parameters, such as reactor pressure vessel (RPV) water level and pressure, and focus on the flowpath for the parameter that is the most off-normal. The values of these parameters indicate which paths the operators should follow, and how far along those paths the operators should be. Often in big-picture flowcharts, an operator will not proceed to the next step in a flowpath unless the situation degrades. By knowing how far from normal a parameter has deviated, an experienced operator will know how far he should be along the flowpath that affects that particular parameter.

However, because the big-picture flowchart approach requires operators to establish priorities between flowpaths rather than to follow only a single flowpath, these flowcharts place a heavier demand on operator training than other procedure formats. There is no question that operator training is a very important element in the safe operation of a nuclear power plant, and that procedures are no substitute. Yet, during stressful situations, human beings function less effectively and are more prone to make mistakes. While procedures can reduce the likelihood of such mistakes, if procedures are to reduce errors, they must be usable by operators who are functioning under stress. Big-picture flowcharts that require concurrent task performance could be more difficult for stressed operators to use. If the procedure reader were to become absorbed in one flowpath to the exclusion of other important flowpaths, there is no mechanism in any of the big-picture flowcharts examined as part of this project that would inform the reader that he should be devoting attention to certain other flowpaths as well. This inappropriate focus on one flowpath (described as "tunnel vision" by one license examiner) may be exacerbated if some of the flowpaths are located on different flowchart sheets.

A second limitation of big-picture flowcharts is that they do not have a true linear branching structure, and so cannot support decision making as well as algorithmic flowcharts. An algorithmic flowchart grows and branches as dictated by the logic of the procedure, with each flowpath branching into (at least) two flowpaths at each decision point. Some of these flowpaths may merge with other flowpaths; others may not. If the procedure contains many branches and the flowpaths do not merge, the resulting algorithmic flowchart will sprawl and snake over the page.

Big-picture flowcharts cannot sprawl over the page in this manner, because an operator executing a big-picture flowchart (or more than one big-picture flowchart, as is often the case) will be in several flowpaths at once. These flowpaths must be simple (1) so that operators can quickly move between them without losing their place; (2) so that the flowchart falls into simple columns on the page, enabling the operators to distinguish between concurrent procedures; (3) so that operators can quickly overview flowpaths as they plan their strategy for concurrently executing the flowpaths; and (4) so that the flowchart is short enough to fit on one page, because the big picture will be lost if the flowchart is broken between pages.

The difference between algorithmic and big-picture flowcharts is shown in Figures 3.13 and 3.14. Figure 3.13 shows a portion of an algorithmic flowchart. A flowchart such as this, as opposed to a text procedure, should certainly reduce errors in decision making, but only at the expense of graphic simplicity. Assume that Figure 3.13 was one of several similar procedures that operators were required to monitor and perhaps perform concurrently. Although decision making is simplified, errors will likely occur because each of the four points in the previous paragraph is violated: (1) operators may lose their place while moving between complex flowpaths, (2) the snaking flowpaths do not fall into simple columns, (3) operators cannot overview the complex flowpaths and quickly see what is ahead, and (4) the flowchart is very large. Figure 3.14 presents the big-picture version of this procedure. The primary difference between Figures 3.13 and 3.14 is that

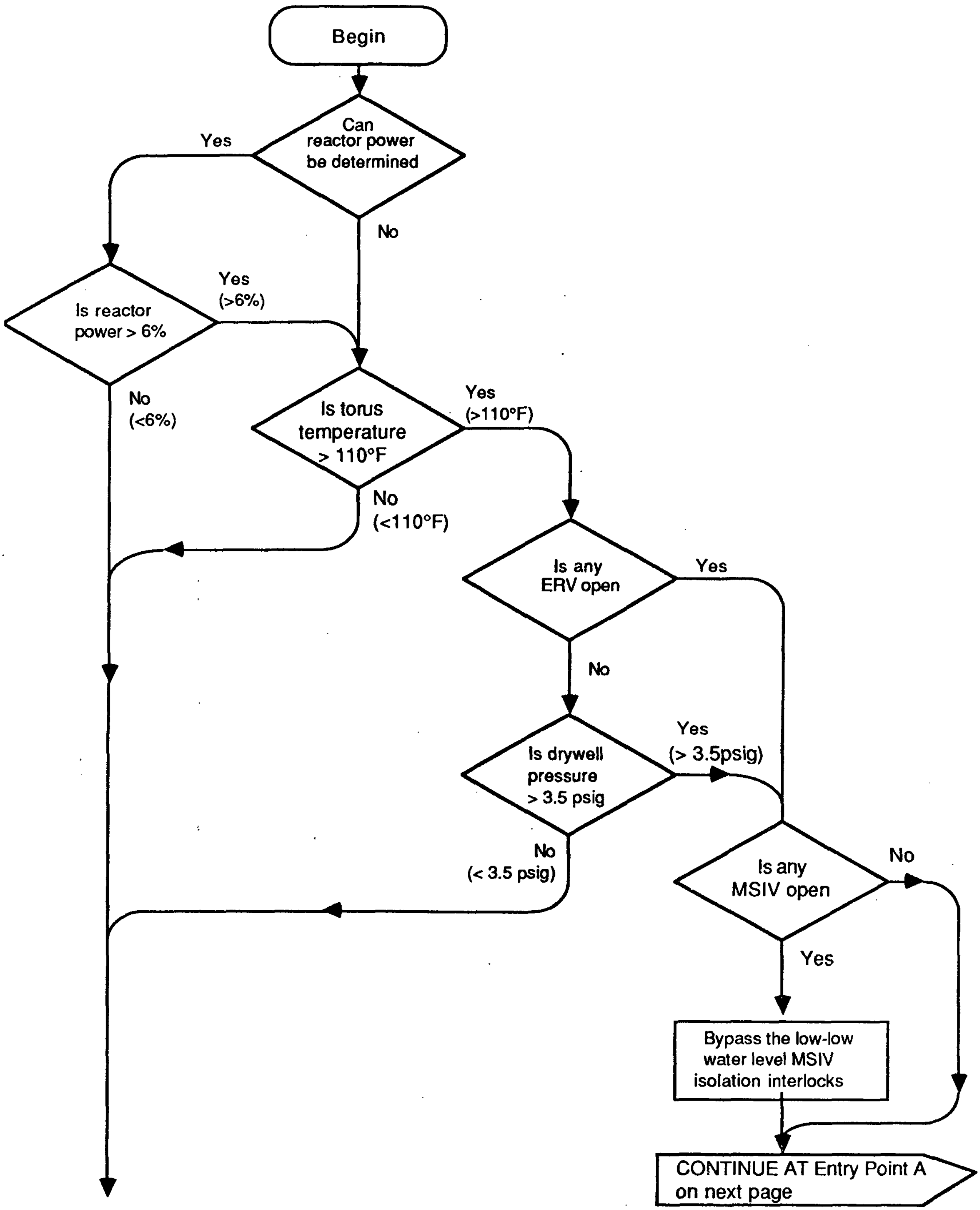


FIGURE 3.13. Traditional Flowchart

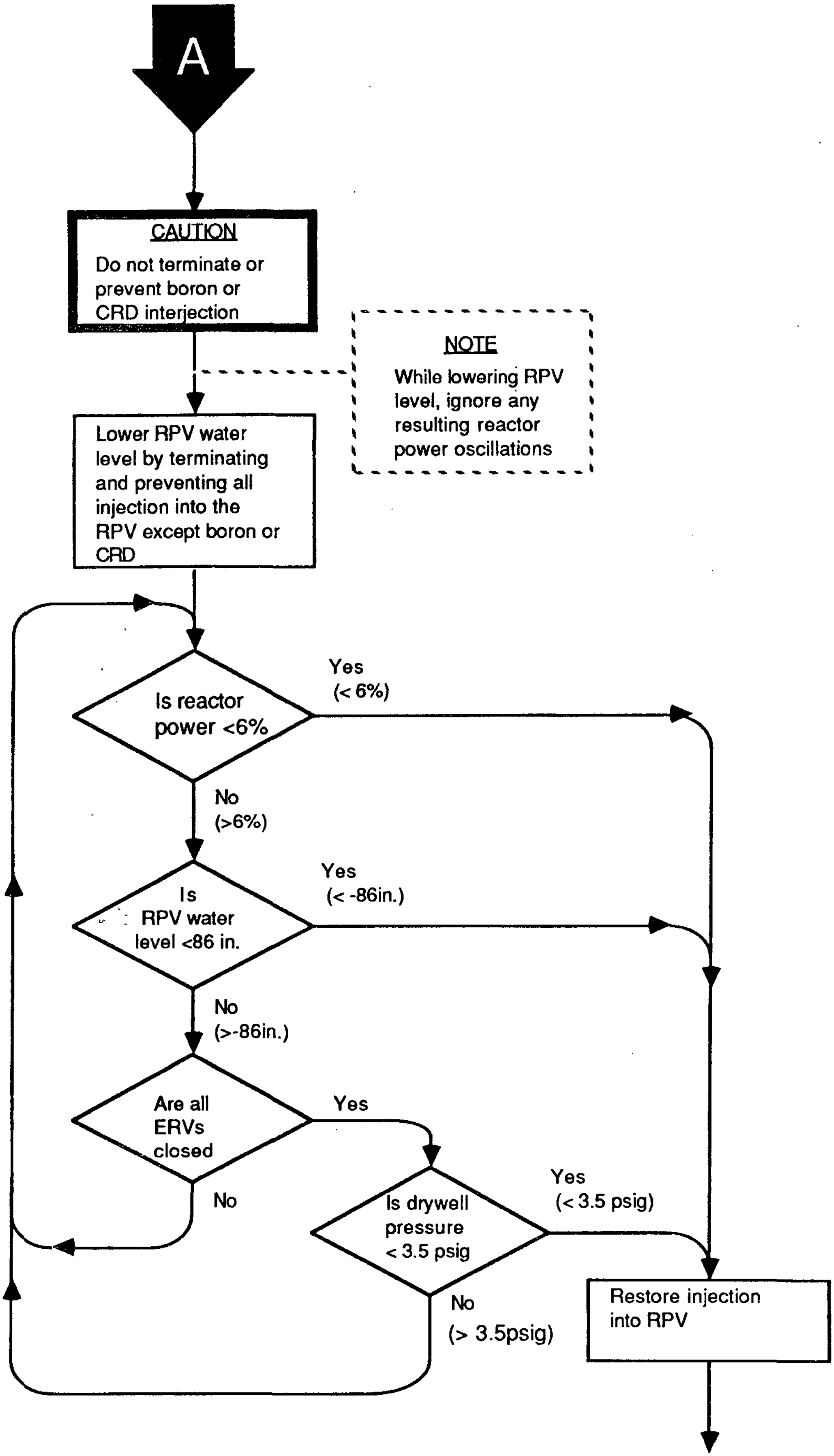


FIGURE 3.13. Traditional Flowchart (continued)

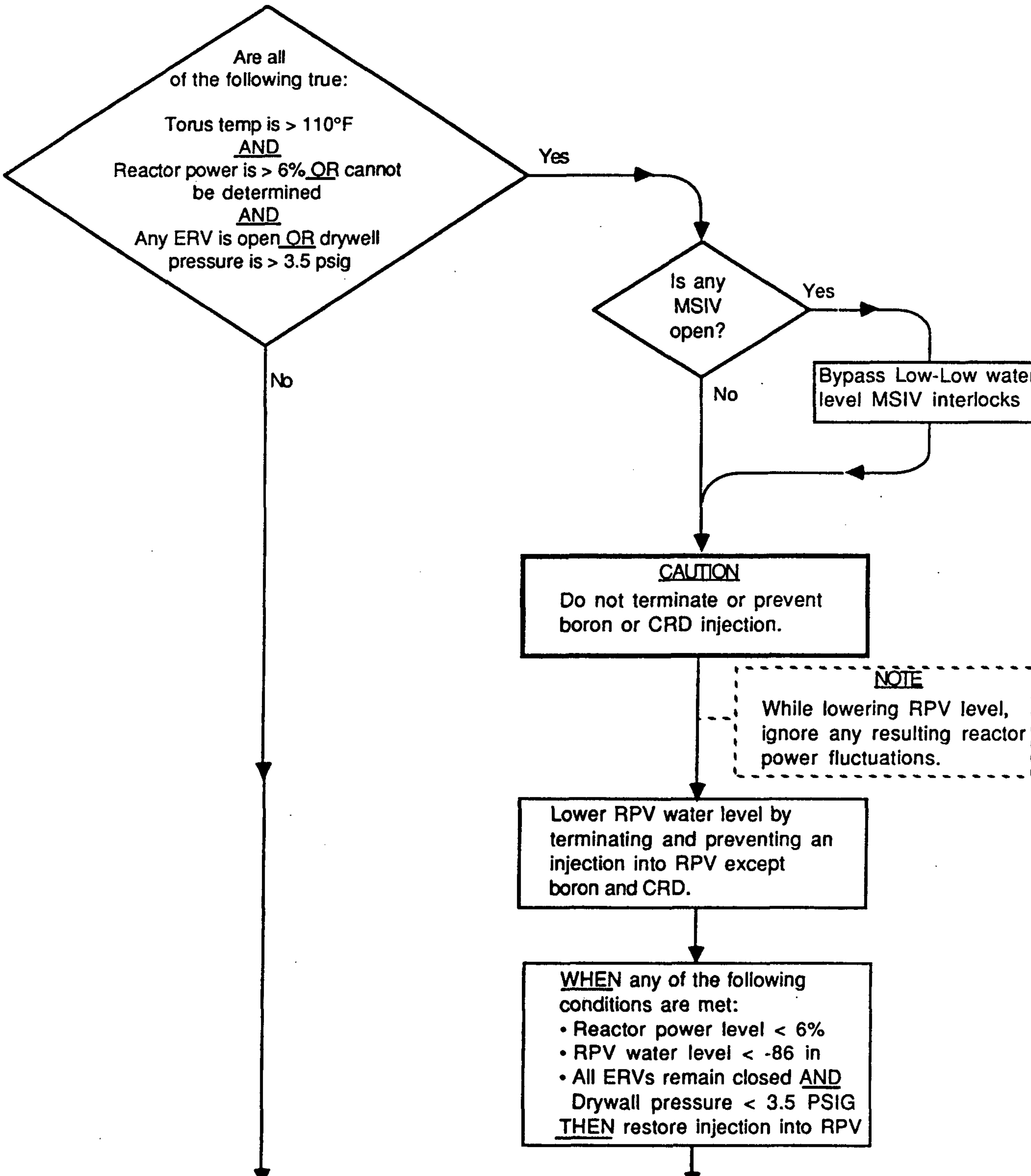


FIGURE 3.14. Big-Picture Flowchart

Figure 3.14 uses logic statements to group decision criteria into one symbol. Although not as strong a decision aid as Figure 3.13, Figure 3.14 is graphically much simpler and will fit more easily into an entire big-picture flowchart.

Because decision criteria are grouped, big-picture flowcharts overcome some of the disadvantages of algorithmic flowcharts that are discussed above: (1) lists of steps can be efficiently presented in big-picture flowcharts, because the lists fall into simple columns; (2) because decision criteria are grouped, their order is not as rigid; and (3), because decisions and actions can be grouped, the relationships between them become more obvious. However, ease and accuracy of decision making certainly suffers. In extreme cases, steps from big-picture flowcharts can be very simple graphically, but can be very difficult to follow. Figure 3.15 shows an example taken from an actual big-picture flowchart that is very confusing; this step, which includes several levels of logic, would be much easier to understand if formatted as an algorithm (as a series of simple decisions).

3.2.4 Summary

In summary, big-picture flowcharts have been developed to meet the specific need in the nuclear power industry to create usable procedures for performing concurrent tasks. They share some of the graphic characteristics of traditional flowcharts, but are more similar to text procedures than to traditional flowcharts. Although they are probably an improvement over text procedures as a method of presenting concurrent tasks, the requirement in big-picture flowcharts for monitoring progress on up to eight flowpaths at once may overload operators. Further, because big-picture flowcharts do not have a linear branching structure, they are not as useful for decision making as are algorithmic flowcharts.

3.3 LEVEL OF DETAIL

The most significant disadvantage of both algorithmic and big-picture flowcharts as EOPs is that the amount of technical information that can be provided to operators is limited. Procedures should contain the minimum amount of detail required to ensure that they can be understood and correctly performed by the intended users. The level of detail that is necessary to support task performance is determined, in part, by the experience, knowledge, and skills of the users. Thus, flowchart EOPs may be appropriate for highly experienced operators, but newly certified operators may need more thorough instructions and additional explanatory material to perform the same task.

It is difficult to present detailed technical information in flowcharts for two reasons: (1) the graphics in the flowcharts occupy space that could be devoted to more detailed information in text procedures, and (2) algorithmic flowcharts, in general, and big-picture flowcharts, in particular, should fit on a single page. To provide additional detail, the writer of a text procedure can simply add another page to the procedure, whereas the flowchart designer must fit both text and graphics into a limited area. To make this

WHEN RPV Pressure falls below the minimum alternate flooding pressure (Table RF-1),

THEN commence and slowly increase injection into the RPV with the following systems:

- Condensate/Feedwater
- CRD
- RCIC
- HPCI
- LPCI

UNTIL

- Reactor power increases and continues to increase

OR

- At least one SRV can be opened

AND

RPV pressure is above the minimum alternate flooding pressure (Table RF-1)

OR

- At least one SRV can be opened

AND

RPV level can be maintained above top of active fuel

FIGURE 3.15. Complex Step from a Big-Picture Flowchart

information fit, the flowchart designer often must eliminate technical detail.

The issue is not only one of limited space, however. Flowcharts do not provide simple mechanisms for the presentation of detailed information. For example, instructions in a text procedure can be presented in a format that includes a higher-level action step followed by a series of detailed substeps that explain how to perform the higher-level step. Alternatively, detailed information can be presented in a right-hand column or on the facing page. The linear branching structure of an algorithmic flowchart makes the presentation of steps and substeps difficult, however. Flowchart designers certainly could not present higher-level steps and substeps as they do in text procedures and connect the steps with flowlines, because operators are trained to execute each step as it is encountered on the flowpath and the inclusion of higher-level steps that are not to be performed might cause confusion. Higher-level steps and substeps can be presented together in one symbol in big-picture flowcharts, but the many steps of this type required in EOPs would not fit on one flowchart page. Further, there are no right-hand columns or facing pages with either type of flowchart.

During an emergency event, operators will be working in a stressful situation and may be under time constraints. These conditions make it difficult for operators to remember what might otherwise occur to them naturally. Consequently, the lack of detail in flowcharts can be serious, particularly if the flowcharts are used by less experienced operators. The lower level of detail in flowcharts must be compensated for by increased operator training and by operator evaluation, so that management and regulators are certain that operators have sufficient knowledge to execute the procedures.

3.4 CONCLUSIONS

There are two functional groups of flowcharts described in the literature: big-picture and algorithmic flowcharts. These two types of flowcharts are designed around different central purposes and thus are very different. Algorithmic flowcharts are useful for presenting EOPs that contain many decisions and so are likely to work well for diagnostic procedures. Big-picture flowcharts are designed to support the concurrent performance of EOPs and so are likely to work well when several procedures that are typically performed together can be presented on the same flowchart page. Because the content and other characteristics of EOPs differ at different nuclear power plants as well as within the set of EOPs at a particular plant, there does not appear to be one best flowchart format for presenting EOPs. Each flowchart type has particular weaknesses, but both algorithmic and big-picture flowcharts share the significant weakness of being able to present only a relatively low level of technical detail. Thus, operator training and experience are of particular importance at sites where flowchart EOPs are used.

4.0 GRAPHICS PRINCIPLES FOR FLOWCHART EOP DESIGN

This section discusses the basic principles of graphic and cartographic design that are applicable to flowchart EOPs. As explained in Section 3.0, a flowchart is a graphic format that is similar to networks and maps. Therefore, principles relevant to the design of these images are especially applicable to flowchart design. Further, the principles of cartography are particularly important because these principles have been more thoroughly examined than perhaps any other type of graphic expression. Maps are one of the oldest graphic representations in existence. For centuries, accurate, understandable maps have been an economic and military necessity. Principles of map design have, therefore, been both thoroughly examined and tested through use.

The cartographic literature suggests that the three most important concerns in the graphic design of flowcharts are (1) legibility, (2) meaningfulness, and (3) aesthetics. Of these, legibility is the most important, given that a flowchart is useless if it cannot be read. Meaningfulness also is important, and refers both to the quantity of information conveyed in the flowchart and the degree to which it is clearly conveyed. Aesthetics must also be considered, because research has shown that people are more prone to use a graphic aid if it is attractive (Benson, 1985).

Specific design principles can be used to address the concerns of legibility, meaningfulness, and aesthetics. Turnbull and Baird (1980, p. 256) describe these design principles as fundamental concerns of good graphic style: "There are standards of style in layout as in writing...these standards--design principles--...[are] contrast, ...proportion, rhythm, ...movement and unity." This section defines these principles, with the exception of movement, which is discussed extensively in Section 5.3.2, and discusses their application to designing flowchart EOPs. The importance of simplicity and consistency in graphic presentations is also addressed. Finally, interactions among graphic elements and trade-offs among the design principles are discussed.

4.1 CONTRAST

The most basic element in any graphic presentation is contrast, for contrast is the essence of vision: we see an object only because it contrasts with its background. Contrast can be created with any of the retinal variables (i.e., value, position, shape, orientation, size, color, and texture) described in Section 5.0. For example, in size variation, large objects contrast with small objects; in shape variation, angular shapes contrast with curved shapes. Turnbull and Baird (1980) explain that contrast is essential to meaning: "Contrast is the source of all meaning. Where is the understanding of 'high' without the concept of 'not high' or 'low'?" (p. 257).

Strong contrasts facilitate perception of flowchart elements. Flowchart symbols, lines, and text must contrast with their background to be easily seen. Flowchart symbol shapes must contrast with each other to avoid confusion.

Contrast can be increased in a flowchart by allowing a light-valued background to surround or lie against the dark foreground created by flowpaths. In graphic design, this use of "white space" is recognized as a powerful and important technique, and can serve several purposes in flowcharts. A small dark area surrounded by a large area of white can appear very pronounced: a sense of importance is implied because it appears that a large piece of the composition has been dedicated to the information. White space can also be used to show organizational information. Items that are logically distinct should be separated with white space.

Contrast draws and holds attention, and so it can be used as an emphasis technique in flowcharts. For example, cautions are frequently emphasized in flowchart EOPs by placing a dark border around the caution symbols. However, dark values will not be as effective at emphasizing flowchart elements if the flowchart is already visually dense: the darker the emphasized areas in a flowchart, the more that darkness will contribute to the visual density of the flowchart. Dark values, such as heavy borders around caution symbols, are, therefore, effective for creating emphasis not because they are dark, but because they are darker than the background against which they contrast.

Strong contrasts should be used in flowchart EOPs to ensure legibility and to enhance the meaningfulness of the graphic elements of the flowchart. If contrast is used properly, it provides information about the items contrasted. If improperly used, contrast can decrease the unity of a flowchart.

4.2 UNITY

Unity refers to the use of visual elements in a graphic presentation to ensure that an image is correctly perceived as a whole. Unity is of particular concern in big-picture flowcharts where the unity of each of the multiple EOPs presented on one page should be emphasized. In algorithmic flowcharts, ensuring that related steps present a unified image can increase the amount of information conveyed by the flowchart. Several techniques can be used in flowcharts to enhance their unity.

Designing flowcharts so that the flowlines are easy to follow creates a strong sense of unity in a flowchart because the flowlines visually tie the different symbols on a flowpath together. The same elements that move the eye through a flowpath also connect the items in that flowpath. However, when implied movement cues (see Section 5.3.2) must be compromised to ensure legibility, the designer must evaluate the compromise in terms of how it impairs the unity of the flowchart. For example, connector symbols such as those shown in Figure 4.1 may be used to minimize the crossing of flowlines, but when using connector symbols, the designer must consider how the symbols will diminish both the sense of implied movement in the flowchart and the unity of the flowchart.

Providing consistent visual patterns throughout the flowchart also creates a sense of unity. The parts of the flowchart that appear to be similar will seem to belong together. Such unity can be achieved by using a small set of flowchart symbols in a consistent manner. Arranging these symbols into a

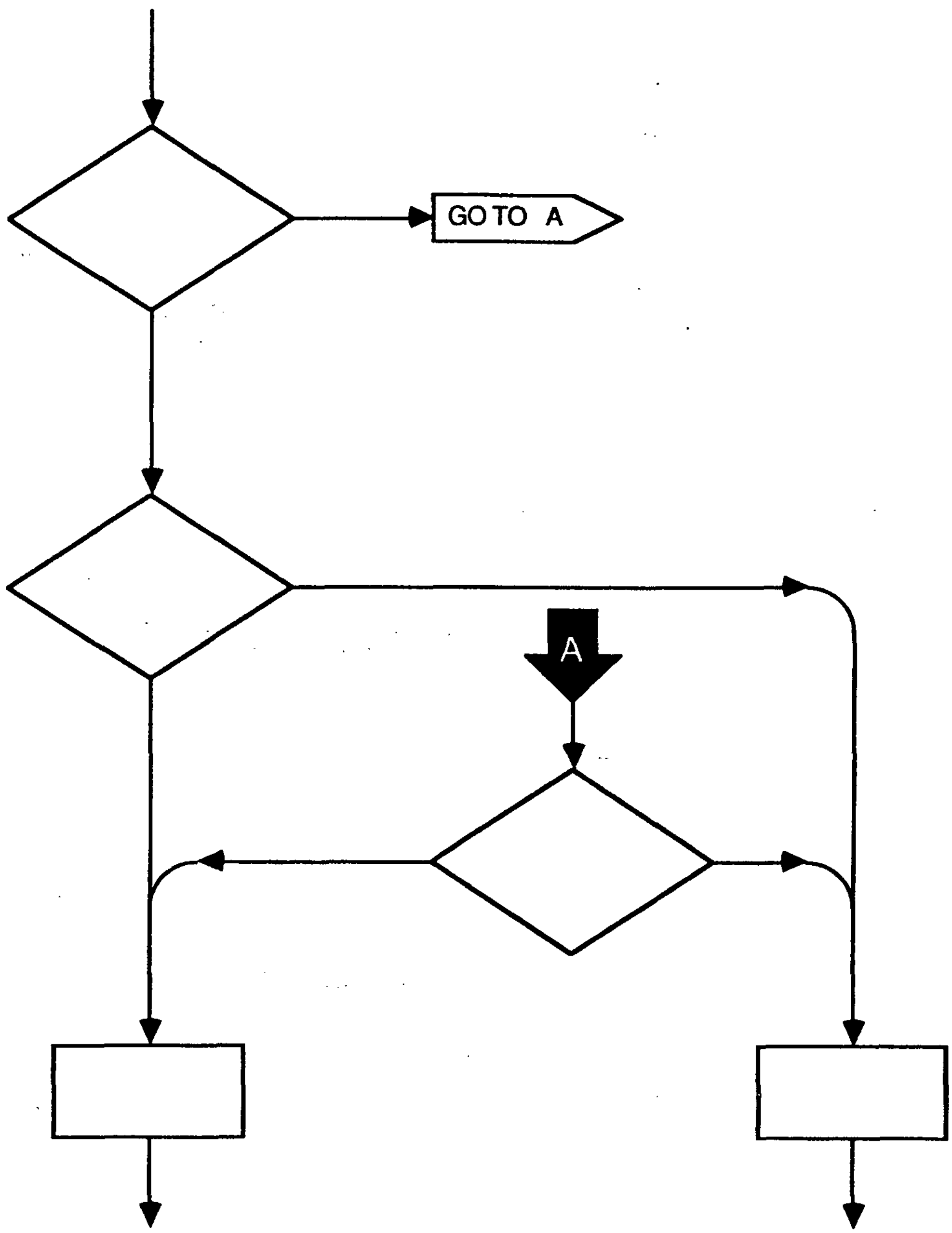


FIGURE 4.1. Connector Symbols Used to Avoid Crossing of Flowpaths

limited number of basic structures (see Section 7.3) can further promote consistent visual patterns.

Unity and contrast often conflict (Misra and Ramesh, 1969). In a highly unified graphic presentation, each piece of the image seems to belong with every other piece. Nothing stands out. Likewise, if contrast is overused, the unity of the image is destroyed. Overused contrast draws attention to itself rather than to the relationships of the items contrasted. When contrast and unity are integrated, however, contrasts are pronounced and obvious but the image of the flowchart is not disjointed, visually disturbing, or overly complex. The elements of the flowchart must be tied together as an integrated whole, but items of importance to the user should be made visually dominant.

4.3 PROPORTION

Proportion is primarily an aesthetic concern; certain proportions are more pleasing to the eye. According to Turnbull and Baird (1980, p. 262), proportion "refers to the relationship of one element to another or to the design as a whole in ratios reflecting size and strength." Proportion, therefore, is a consideration when designing the overall shape of a flowchart and all of the aspects of the flowchart that can be varied (e.g., the positioning of symbols and flowlines, and the sizes, shapes, and values of those symbols and lines).

Turnbull and Baird (1980), Dondis (1973), and Bertin (1983) all discuss how proportions that are not obvious to the eye are more effective graphically. Proportions of (or near to) 1 to 1 and 2 to 1, for example, are less attractive than the proportion of 3 to 1 (Turnbull and Baird, 1980).

In flowcharts, however, the size of a symbol is often dictated not by the rules of proportion, but by the amount of text that the symbol must contain and the size of the flowchart. If the flowchart designer is able to consider proportion when developing a flowchart, he or she should take care that proportional variations do not convey false graphic cues. In other words, a large symbol that is pleasingly proportioned might draw undue attention to the information that it contains because of its size.

4.4 RHYTHM

Rhythm is achieved in graphic design through the orderly repetition of any graphic element. Rhythm is closely tied to movement; the eye tends to follow any clear rhythm in a graphic presentation. An example of effective use of rhythm in flowcharts is the consistent spacing of arrows along flowlines. The arrows should form a pattern that leads the eye through the flowpath.

4.5 CONSISTENCY

Literature from the fields of technical communication, graphic design, cognitive psychology, and computer programming all indicate that it is critical for information to be presented consistently for clear communication

(Williges and Williges, 1984; Fisk, Ackerman, and Schneider, 1987). As Farkas and Farkas (1981) explain in the context of text communications:

> Every manuscript contains mechanical elements of numerous kinds: abbreviations, hyphenated compounds, numerals, spelled numbers, and so forth. The editor must ensure that throughout the manuscript these recurring elements are treated consistently, that is, in a uniform or else logical and harmonious way. The human mind has an inherent need for order, and if these elements are not treated consistently, the reader may perceive the document to be disorderly and unprofessional or may be distracted by the inconsistencies. Worse still, in some instances, the inconsistent treatment of mechanical elements can be genuinely confusing, because the reader may assume that two treatments of the same thing indicate some distinction in meaning that the reader has failed to understand. (p. 16)

Bertin (1983) points out that graphic conventions must be treated with the same consistency as the mechanical elements of text described above.

Graphic design uses variation (change) to convey meaning, and so it is important that only meaningful variation is used in a flowchart. The flowchart user has no way of distinguishing accidental changes from deliberate changes in aspects of the flowchart such as type size, line widths, and so on. The flowchart user is forced to provide his or her own interpretation of the meaning of unintentional changes and may become confused.

Conventions of presentation, be they textual or graphic, then, are only meaningful when they are used consistently. Graphic inconsistencies will obscure graphic cues, and may lead operators to mistakenly read meaning into random graphic elements. Thus, inconsistencies will reduce the meaningfulness of a flowchart and they may cause operator errors.

4.6 SIMPLICITY

One of the most important principles of good graphic design is that the graphic representation should be as simple as possible. Dondis (1973) lists simplicity as one of the primary "techniques" of functional graphics. Bailey (1982) points out that it is important that job performance aids, such as procedures, not only be simple but "<u>appear</u> clear and simple at first glance, so people will want to use them" (p. 457). Bertin (1981) stresses that it is especially important that graphics such as flowcharts be presented in the simplest format possible: "A network is often complex itself, so it is necessary to eliminate all needless complexity" (p. 131).

Every item included in a flowchart contributes to the complexity of the flowchart. Nothing should be included in the flowchart unless it provides necessary information (Bertin, 1981; Tufte, 1983). Bertin (1981, 1983) describes two techniques that can be used to simplify graphic presentations such as flowcharts. He notes that graphics can be simplified by "transformation" and by "design."

Simplification by transformation entails more global design considerations than does simplification by design. Simplification by transformation is the process of arranging the flowchart elements on the page so that they provide the simplest representation of the relationships among those elements. This entails placing items so that meaningful orders and meaningful relationships are clearly and simply shown. An example of simplification by transformation is structuring a flowchart so that it is made up only of the basic structures described in Section 7.3.

Simplification by design is essentially a process of reducing the number of visually complex elements in the flowchart. Two examples of simplification by design are (1) arranging the items in the flowchart so that needless angles are removed from flowlines, and (2) condensing parallel flowlines that end in the same symbol into one flowline.

4.7 INTERACTIONS OF GRAPHIC ELEMENTS

A final consideration in applying the principles of graphic design to the development of flowcharts is that every feature in a flowchart affects how other features are perceived. Misra and Ramesh (1969) notes that graphic designers must be aware of how an individual item in a graphic representation interacts with other items that are placed near it on the visual plane.

> The positioning of symbols in association with various types of different lines produces different perceptions. For example, if a bending man is shown above a diagonal, he appears to be picking up something from the ground. But if he is placed beneath the diagonal, he appears to bend under the weight of space above him.... Several lines put together in different orders produce different perceptions. Lines forming various shapes, like squares, triangles, etc., lose their existence altogether. When we see a triangle, we never perceive it to be three lines put in a certain order. We see a figure. (p. 249)

The failure to consider interactions among flowchart elements can result in visual illusions and distortions in the information conveyed by a flowchart. For example, consider the famous Muller-Lyer arrows figure shown in Figure 4.2. In Figure 4.2, the arrow is placed exactly in the middle of the line. The two line segments between the arrows appear to be different lengths because the arrows change our perception of the line segments. Gregory (1970) stresses that the potential problems caused by such illusions should not be underestimated. "In distortion-illusion figures, some lines appear too long or too short, others bent, while still others are displaced from their true positions. The errors can be as great as 30 percent or even more; quite large enough to be serious in practice" (p. 79).

Although graphically complex flowcharts are more subject to such illusions, visual illusions and distortions can also occur in very simple flowcharts. Even simple flowcharts may create figure/ground illusions, such as that shown

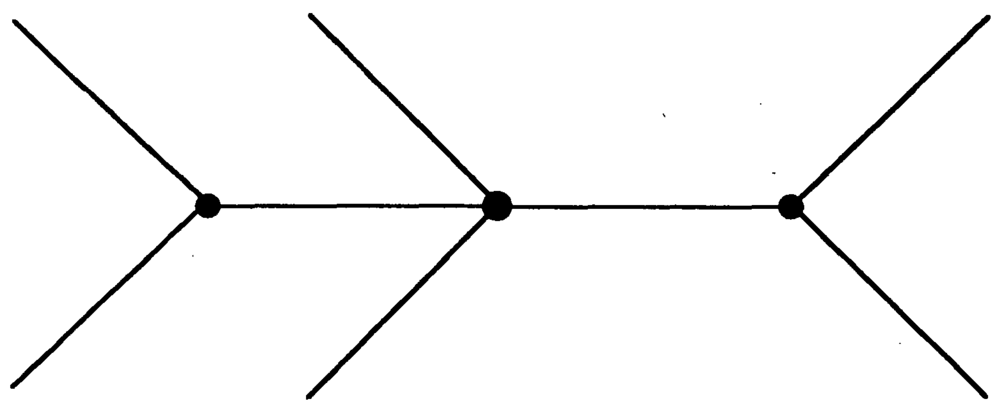


FIGURE 4.2. Muller-Lyer Arrows Diagram

in Figure 4.3. This figure can either be perceived as two faces in profile or as a vase, depending upon which elements of the image are regarded as part of the figure and which elements are regarded as part of the background.

Figure/ground illusions occur when there is a lack of contrast between the foreground figures and the background areas in a graphic representation. The greater the contrast, the more clearly foreground shapes emerge from the background (Wood, 1968). When the background contains a level of detail comparable to the foreground, a reversible figure/ground relationship will exist.

Obviously, clear figure/ground differentiation is important in flowcharts so that actual errors do not occur, such as an operator skipping a step because he perceives it as a background shape rather than as a foreground symbol. If large pieces of text are placed outside of symbols, however, an opportunity for figure/ground distortions exists. Figure/ground distortions can also be created when flowlines form a figure that is a shape, or is similar to the shape of a flowcharting symbol. Constructing flowlines without angles and ensuring that they do not cross other flowlines can avoid this sort of distortion.

The shape of blocks of text within flowchart symbols is another example of how flowchart elements can interact to either obscure or clarify the information in the procedure. Turnbull and Baird (1980) point out that the major weight of the block of text should be above the center of the block. Alternating long and short lines of text should be avoided because this makes it especially difficult to sense the shape of the block of text. Consider the ways in which text could be arranged in a diamond-shaped flowchart decision symbol in the examples shown in Figure 4.4.

The text in the first example, arranged with alternating short and long lines, creates confusing visual cues. The block of text does not in any way indicate a diamond shape. In the second example, the text is concentrated in the bottom half of the diamond-shaped symbol and more clearly indicates the diamond shape of the decision symbol. In the third example, the block of text is even more diamond-shaped and the text block is shaped as a slightly top-heavy diamond. This arrangement most clearly reflects the diamond shape of the decision symbol, and interacts with the symbol itself to create a legible, meaningful, and aesthetically pleasing configuration on a flowchart.

The visual features of a well-designed flowchart accent and compliment each other. Such a chart is aesthetically pleasing and it is capable of conveying information graphically. By contrast, in a poorly designed flowchart the features may compete with each other or contradict each other. Such a flowchart will not convey information clearly, and the graphics may provide inaccurate or false visual cues. Therefore, the flowchart designer must consider how graphic elements interact in a flowchart and how well they function as a combined unit.

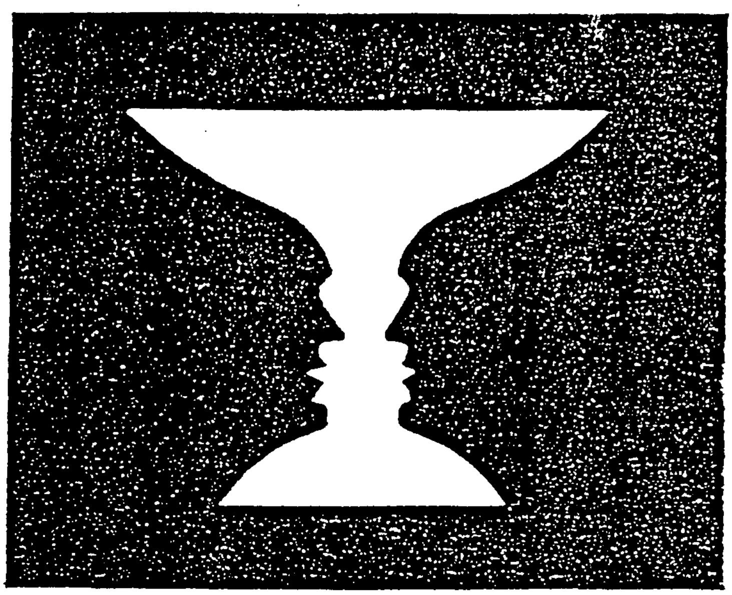
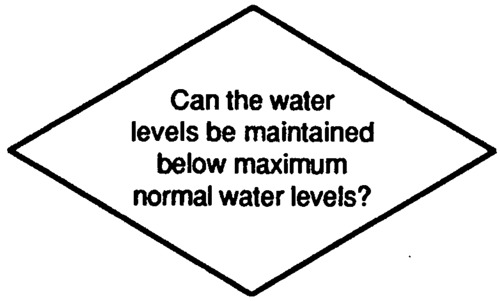
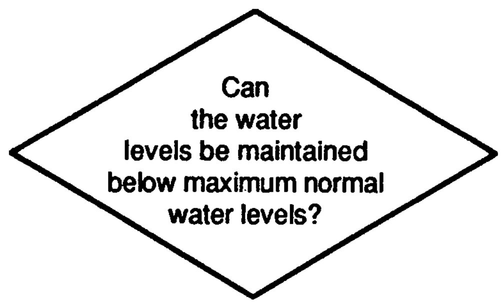


FIGURE 4.3. Figure/Ground Illusion

Example 1:



Example 2:



Example 3:

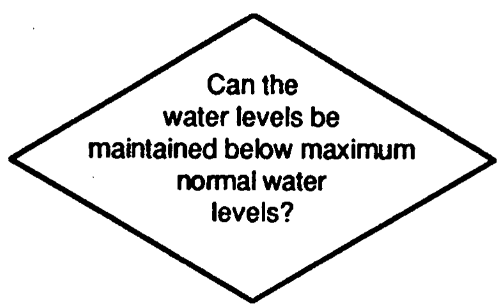


FIGURE 4.4. Blocks of Text in Decision Symbols

4.8 TRADE-OFFS AMONG DESIGN PRINCIPLES

It is also important to note that, on some occasions, compromises must be made between legibility, meaningfulness, and aesthetics. These compromises, however, must preserve the importance of legibility over other concerns.

In some flowchart EOPs examined, legibility was incorrectly sacrificed for meaningfulness. For example, Figure 4.5 shows an excerpt from a flowchart EOP where legibility and meaningfulness interact. In this example, a reference symbol has been oriented to point upward in the chart. The upward direction indicated by the symbol is meaningful in that it shows the flowchart user the direction to follow to find the referenced information. However, the text in the symbol in Figure 4.5 is oriented vertically rather than horizontally, and so is harder to read. The more legible design in Figure 4.6, therefore, is the preferred design for this reference step.

Flowchart designers will constantly make such trade-off decisions among flowchart design principles. To create flowcharts that are usable, however, the flowchart designer must ensure that the legibility of the flowchart is given first priority, that the meaningfulness of the graphic elements used is considered next, and that the aesthetic characteristics of the flowchart images are considered as well.

4.9 SUMMARY

The flowchart designer must consider six principles of graphic design to ensure that flowchart EOPs are legible, meaningful, and aesthetically pleasing. These principles are (1) the amount of contrast between flowchart elements, (2) the graphic unity of flowchart elements that are related, (3) the proportions of flowchart elements, (4) rhythm in the presentation of repeated items, (5) consistency in the conventions used to communicate procedural information in the flowchart, and (6) simplicity in the graphics (and text) of the flowchart. In addition, to avoid visual illusions and distortions and to ensure that the information provided by the graphics of the flowchart reinforces the information provided by the text, flowchart designers should consider the manner in which flowchart elements (such as symbols, flowlines, and text) interact. Finally, the flowchart designer will often be faced with conflicts between the principles of graphic design when developing flowcharts, but must remain aware of the relative importance of legibility, meaningfulness, and aesthetics in the trade-off decisions made.

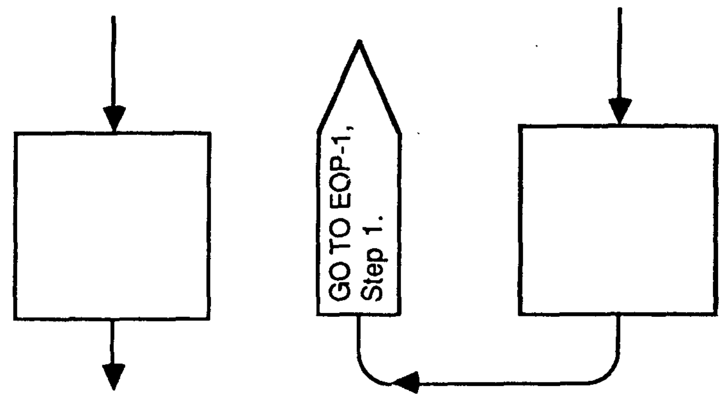


FIGURE 4.5. Interaction of Legibility and Meaningfulness: Meaningfulness Given Prominence

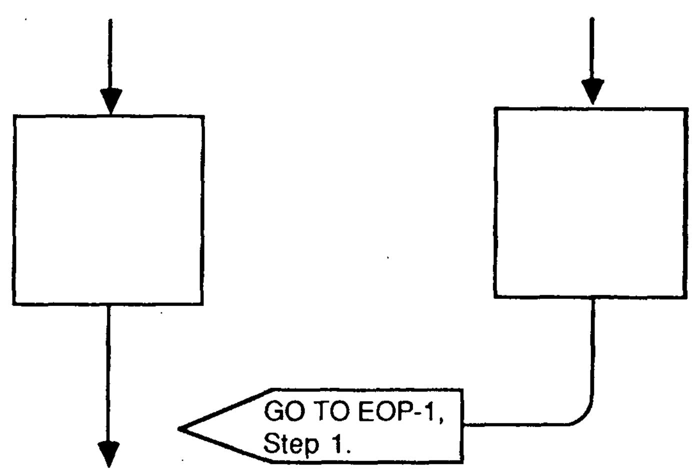


FIGURE 4.6. Interaction of Legibility and Meaningfulness: Legibility Given Prominence

5.0 VISUAL VARIABLES

This section discusses the specific characteristics of a graphic composition that can be manipulated to convey information. These characteristics are known as visual variables. In this section, the general types of information that can be communicated graphically by each variable, as well as specific applications of each variable in flowchart design, are discussed. Potential misuses of the visual variables are also examined.

5.1 AN OVERVIEW OF THE VISUAL VARIABLES

The eight visual variables that can be manipulated in flowcharts to convey information graphically are position, implied movement, shape, orientation, size, value, color, and texture (Bertin, 1981, 1983). These visual variables can be divided into two categories: planar variables and retinal variables. The planar variables (position and implied movement) change the appearance of the entire flowchart when manipulated. The retinal variables (shape, orientation, size, value, color, and texture) have a less global impact on a flowchart and are used to change the appearance of points, lines, and areas within the flowchart.

It is important to recognize that the visual variables are the methods of changing flowchart elements, rather than the items that are changed. For example, a point is a position on the plane that has no theoretical area. However, the mark that renders the point visible does occupy area, and the mark can vary in size, shape, value, or color. Likewise, a line has a given length but theoretically no width, however, the mark that renders the line visible may vary in size (width), value, color, and so on. An area has measurable size. The mark representing the area cannot change in size, shape, or orientation without changing the area itself. However, the mark may vary in value, texture, and color.

Position variation and implied movement, as planar variables, operate at a more primary level than the other visual variables. After symbols are placed on the flowchart sheet and connected with flowlines, the other variables (shape, orientation, texture, value, and size) can be used to clarify, reinforce, or augment the information already provided by the position of the flowchart symbols and the flowlines that connect them.

5.2 TYPES OF INFORMATION CONVEYED THROUGH THE VISUAL VARIABLES

A visual variable may convey ordered information, quantitative information, associative information, dissociative information, or selective information (Bertin, 1981, 1983). Each variable has different strengths and weaknesses with regards to how clearly it conveys each type of information. For a variable to convey a given type of information well, the meaning of the variation must be obvious. According to Bertin, only position variation is capable of conveying all of these types of information clearly. For some of the retinal variables, whether or not the variable can convey a particular type of information depends on which planar representation is being varied: a point, a line, or an area.

This section presents the different types of information that can be conveyed by manipulating each of the visual variables in a flowchart. The preferred method for presenting each type of information in flowcharts is also discussed.

5.2.1 Ordered Information

Ordered information is conveyed when items can be easily placed in a predicted sequence. When using a variable to provide information about order in a flowchart, the order of the items should be obvious without consulting a legend.

Size, value, and texture are ordered regardless of whether points, lines, or areas are varied. Size is ordered from large to small (or from small to large), value is ordered from dark to light (or light to dark), and texture is ordered from coarse to fine (or fine to coarse). Within the two dimensions of the plane of a flowchart, information can be ordered from top-to-bottom, or from left-to-right. The natural tendency of these variables to convey ordered sequences can be used to convey any sort of hierarchical relationship. A fundamental way in which items are ordered in EOPs is sequentially, i.e., from first to last. However, other orders can be shown graphically as well, such as the orders from most to least important, from most general to most specific, and from optimal to least preferred.

Color, orientation, and shape are not ordered variables. These variables can be used to convey information about how a set of items is ordered, but the order will not be obvious. Special care must be taken when a non-ordered variable is used to convey ordered information in a flowchart to ensure that the order is unambiguous. Additionally, operators must be trained to understand the sequence of such variables, since no intrinsic order exists. For example, using borders of different colors to form caution and note symbols, where color is used to indicate the importance of the information contained in the caution or note, would require training operators to interpret the meaning of the colors used.

5.2.2 Quantitative Information

Quantitative information is conveyed when the distance between two items in an ordered sequence can be expressed as a numeric ratio. That is, not only is it readily clear that A is larger or greater than B, but it is clear that A is twice the size or value of B. Of the visual variables, only size can be used to convey quantitative information, and size can only display such information with a limited degree of precision. Quantitative information is most reliably expressed through text and numbers. Text and numbers should therefore be used to display quantitative information in flowcharts.

5.2.3 Associative and Dissociative Information

Associative and dissociative information are particularly important in the design of flowcharts. Manipulation of the visual variables to convey associative or dissociative information can sometimes replace the need for text in flowcharts or can reinforce the information presented in the text.

Associative information is conveyed when two or more variables are used together and one or more of the variables can be ignored. The variable that is ignored is said to be associative. For example, squares, circles, and triangles that are black and of the same size can be seen as being similar, as forming an association. Shape variation has been ignored. Although each item is of a different shape, they are associated through their similar sizes and identical values (black). Shape, therefore, is associative.

An example of the effective use of shape to convey associative information in flowcharts is the shape coding of symbols. To follow the flow of information along a flowpath, the operator must be able to associate all of the information as belonging together regardless of the fact that different symbol shapes are used along the flowpath.

If a particular type of variation cannot be readily ignored, it is dissociative. A dissociative effect is not only difficult or impossible to ignore, it is immediate. A good example of the immediate nature of dissociative effects can be seen in musical notation. In musical notation, value variation (lightness or darkness), which is dissociative, is used to indicate the timing of the music. Short notes require more ink, so that the darker the sheet of music is, the faster the music moves. This convention provides information about the speed of the music that can be gleaned at a glance. In a graphic presentation, a dissociative variation is noticed before any other type of variation.

The distinction between associative and dissociative information can be seen in Figure 5.1. In Figure 5.1 it is easy to "associate" the small shapes, and to discern which areas of the figure contain a predominance of small shapes. It is equally easy to discern which area of the figure has a predominance of large shapes. It is only possible to discern these patterns because, when viewing the figure, one can ignore the variations in shape within the figure and focus on the size variation. It is very difficult, however, to focus one's attention on the shape variation and to ignore the size variation. It is difficult, for example, to discern which areas of the figure contain a predominance of rectangles. Therefore, shape variation in this figure is associative, and size variation is dissociative because it cannot be easily ignored.

The associative or dissociative nature of a variable does not depend on whether points, lines, or areas are varied. According to Bertin (1981, 1983), shape, orientation, color, and texture are always associative. Value, size, and implied movement are always dissociative.

The dissociative nature of value, size, and implied movement is an important consideration in flowchart design. Variations in value, size, and implied movement will dominate over other graphic variations in the flowchart, as shown in Figures 5.2 and 5.3. In both of these figures the series of dots form rectangles, and flowlines have been added to the figures to direct the viewer's eye through the images. In Figure 5.2, the rectangular area defined by the dots is readily apparent. The flowlines in fact reinforce this image. The flowlines in Figure 5.3, however, obscure the fact that the dots occupy

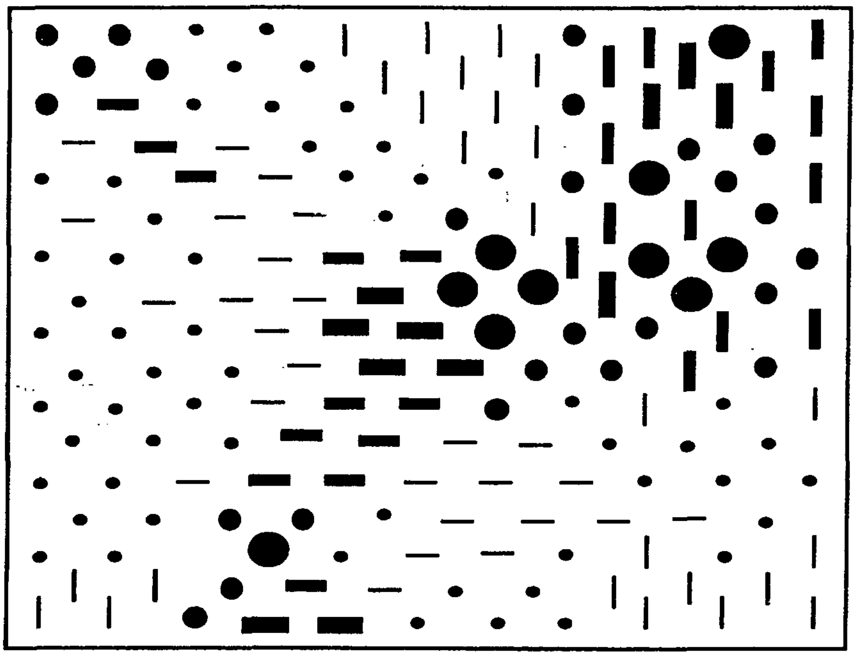


FIGURE 5.1. Associative Nature of Shape Variation; Dissociative Nature of Size Variation

Source: Adapted from Semiology of Graphics Diagrams Networks Maps (p. 64) by J. Bertin (W.J. Berg, Trans.), 1983. Madison: University of Wisconsin Press.

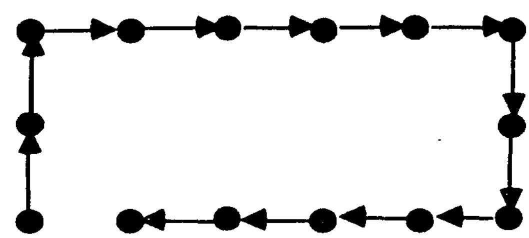


FIGURE 5.2. Implied Movement Emphasizes Rectangular Shape

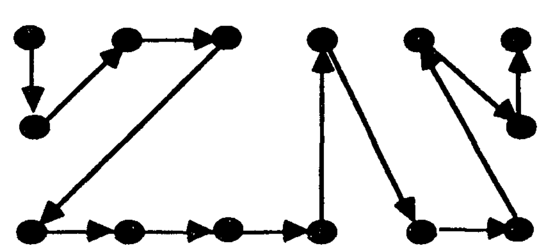


FIGURE 5.3. Implied Movement Obscures Rectangular Shape

an area of rectangular shape. Therefore, the movement implied by the flowlines has a dissociative nature that dominates the associative information provided by the shape of the dots.

When used well, the dissociative nature of value, size, and implied movement accents and draws attention to important information. When the dissociative effects of these variables are not considered, changes in value, size, and implied movement may mask other important graphic cues or create false graphic cues. For example, a large flowchart symbol will draw attention and appear to be important, even if it has been drawn large only because it must house a large block of text. Finally, because size, value, and implied movement cannot be ignored, it is unlikely that operators could be easily trained to disregard them in a flowchart.

5.2.4 Selective Information

Selective information is conveyed when items can be identified as being related to each other through a given variable. Although associative and selective information both involve the linking of related items, they are very different.

- In associative relationships, several items are associated together in spite of differences they have with respect to the variable in question.

- In selective relationships, an individual item can be isolated and selected as being a member of a specific group because of similarities it shares with other members of the group with respect to the variable in question.

Use of the visual variables to convey selective information allows the viewer to isolate all items in a set such as the set of dark signs, the set of green objects, or the set of shapes at the top of the visual field. An example of a good use of selective information in flowcharts is the manipulation of the widths of decision and action symbols, so that all symbols on a flowpath are of the same width. Along with the cues provided by the position of the flowchart symbols and the graphic tie that the flowlines provide, this use of size variation informs the operator that all of the symbols on that flowpath belong together.

The clearest presentation of selective information is provided by using position variation to reveal relationships among flowchart elements. By placing related items together, and separating unrelated items with white space, it is easy to see to which group an item belongs. Figure 5.4 demonstrates that position does an excellent job of showing selective information: the three groups of dots have been separated by position, but the basic shape created by each group of dots is easily seen.

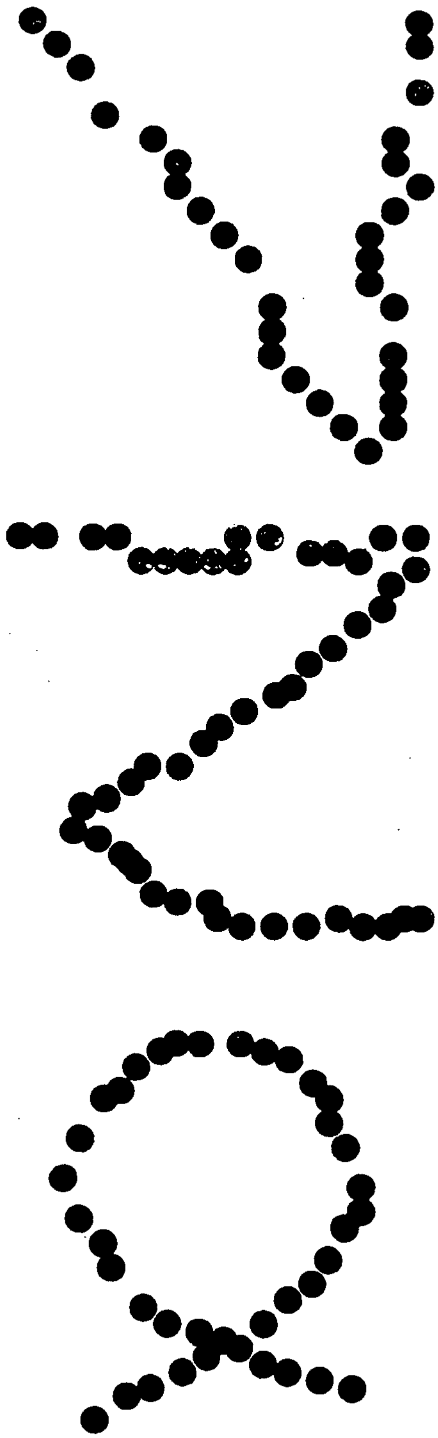


FIGURE 5.4. Selective Nature of Position Variation

Source: Adapted from Semiology of Graphics Diagrams Networks Maps (p. 67) by J. Bertin (W.J. Berg, Trans.), 1983. Madison: University of Wisconsin Press.

Size, value, texture, and color can also convey selective information, although less clearly than position. For example, in Figure 5.5, the three sets of dots from Figure 5.4 have been superimposed on each other, and size variation, rather than position variation, has been used to define each set of dots. The shape presented by each set of different-sized dots can still be perceived in Figure 5.5, but not as readily as when position is used.

Orientation, implied movement, and shape are less effective methods for providing selective information. Orientation can be used to show selective information for points and lines, but does not show selective information when areas are manipulated. Implied movement has, at best, only a limited selective nature. Selective information cannot be unambiguously portrayed with shape variation, as shown in Figure 5.6. In Figure 5.6 the shape of the dots shown in Figures 5.4 and 5.5 has been used as a visual cue rather than position or size. The patterns that could be seen in Figures 5.4 and 5.5 are no longer evident. Therefore, shape is not selective.

Bertin (1983) provides a test for selectivity as follows: images should be separated by a single variable. If the individual images can be perceptually separated, that variable is selective. Figures 5.7 and 5.8 apply this test to the graphic elements that show implied movement. This test assesses the ability of flowlines, without position cues, to convey selective information. Figure 5.7 shows two flowpaths with position used as a visual cue. In this figure the flow of movement through each chart can be easily seen; all flowpaths can be selected. In Figure 5.8, the flowpaths have been superimposed and only the flowlines direct movement through the charts. In Figure 5.8 the flow of movement through each chart cannot be easily seen; all flowpaths cannot be selected. Therefore, position is selective, but implied movement is not. The devices used in these flowpaths to show implied movement, other than position, are not in themselves strong enough cues to guarantee that each flowpath will be correctly selected.

To ensure that flowlines can be readily and accurately selected, the cues provided by flowlines must be enhanced through the use of another visual variable. Variations that can be used to enhance flowline selectivity include position variation (separating parallel flowlines with white space and minimizing the crossing of flowlines), size variation (varying the thickness of flowlines), and color variation (color coding the flowlines). Of these options, position variation is the most reliable means of separating items such as flowpaths (Chapin, 1974; Bertin, 1981, 1983).

When combined with position cues, flowlines can do an excellent job of showing some types of selective information. For example, in Figure 5.9 the steps to be repeated in the loop are easily perceived. A flowline connects the steps, and the looping flowline literally frames them. The steps are <u>associated</u> together by the frame created by the loop. Additionally, while performing any individual step within the loop, an operator can glance to the side of the step and see the loop. It is therefore easy to <u>select</u> any individual step as one of the steps in the set of repeated steps. Symbols should be positioned, and flowlines should be constructed, to show relevant selective information whenever possible.

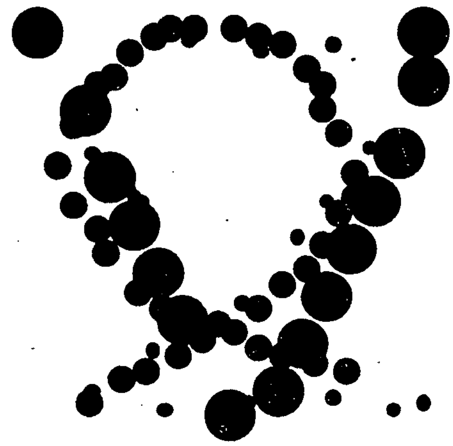


FIGURE 5.5. Selective Nature of Size Variation

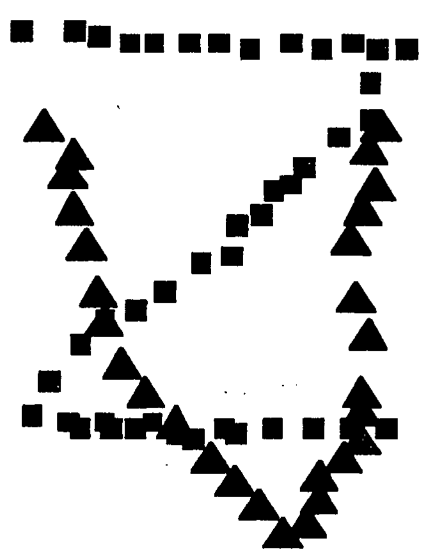


FIGURE 5.6. Shape Cannot Show Selective Information

Source: Adapted from Semiology of Graphics Diagrams Networks Maps (p. 68) by J. Bertin (W.J. Berg, Trans.), 1983. Madison: University of Wisconsin Press.

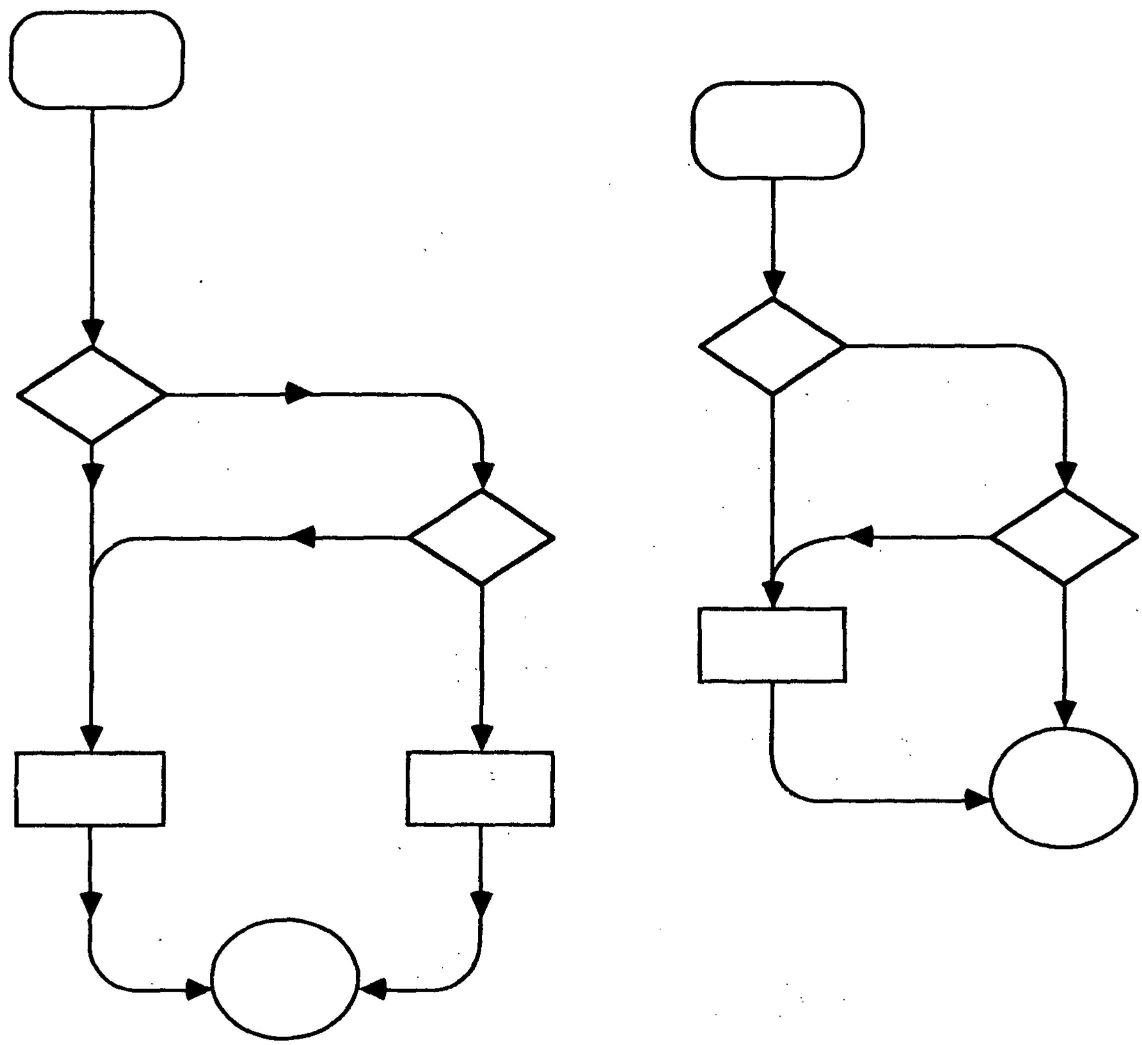


FIGURE 5.7. Two Flowpaths with Position Used as a Visual Cue

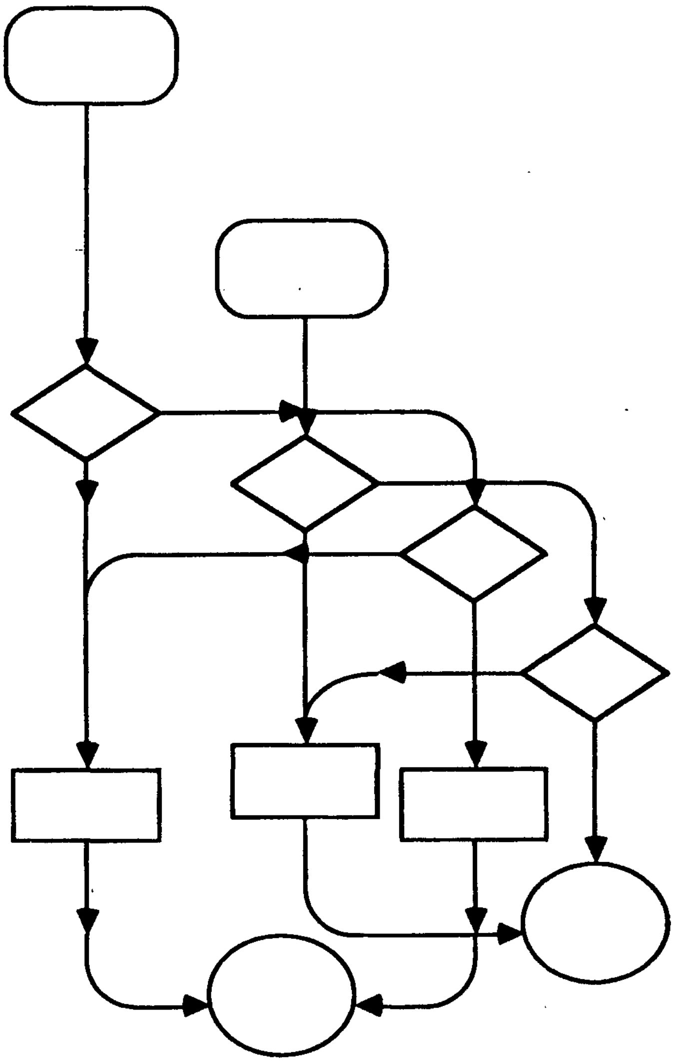


FIGURE 5.8. The Two Flowpaths in Figure 5.7 Superimposed on Top of Each Other

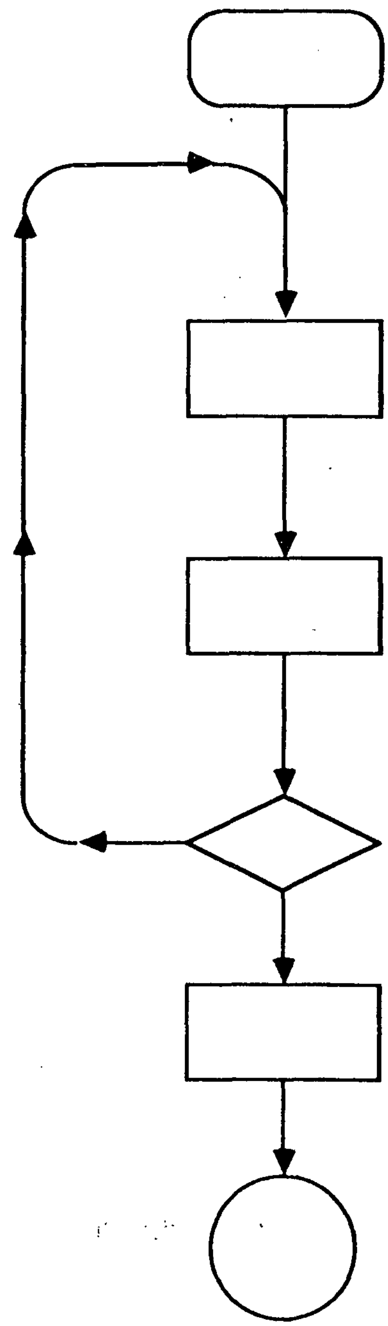


FIGURE 5.9. Use of a Flowline to Associate Steps in a Loop

5.2.5 Types of Information Conveyed Through Visual Variables: Summary

The types of information that can be conveyed through each of the visual variables are shown in Table 5.1. This table shows which variables can convey the different types of information, and, for the retinal variables, whether this information can be conveyed through the manipulation of points (p), lines (l), or areas (a).

TABLE 5.1. Types of Information Conveyed by the Visual Variables

	TYPE OF INFORMATION			
	Ordered	Associative	Dissociative	Selective
Planar Variables				
Position	YES	YES	NO	YES
Movement	limited	NO	YES	NO
Retinal Variables				
Shape	NO	p l a	NO	NO
Orientation	NO	p l a	NO	p l
Size	p l a	NO	p l a	p l a
Value	p l a	NO	p l a	p l a
Color	limited	p l a	NO	p l a
Texture	p l a	p l a	NO	p l a

5.3 USE OF THE VISUAL VARIABLES IN FLOWCHARTS

Each of the visual variables can be used to develop effective flowchart EOPs. In this section recommendations for using the visual variables to design flowchart EOPs are presented. In addition, examples of misapplications of the visual variables are discussed.

5.3.1 Position

The position of flowchart elements is the most important visual variable to be considered in designing flowchart EOPs. As can be seen in Table 5.1, position is an extremely powerful variable, able to show associative, selective, and ordered information for points, lines, and areas. In addition to the role that position plays in defining the basic sequence of decisions and actions in a flowchart, position is also an important consideration in presenting cautions, notes, figures, and tables. Because it is the most important concern in flowchart layout, positioning flowchart elements is discussed extensively in Section 6.0, rather than here.

When using position as a visual variable, however, flowchart designers should ensure that the ways in which flowchart elements are positioned create consistent visual patterns throughout a flowchart. As explained in Section 4.5, following consistent conventions in flowchart design increases the usability of the flowcharts. For example, in a multiple-column algorithmic flowchart, connector symbols can be used to indicate that the operator is to move from the bottom of one flowpath to the top of the next flowpath. This convention makes it easy to "select" where to look for an entry connector symbol, as the symbol would consistently be at the top of the column to the right of the column that ends with the corresponding exit connector symbol. Another example of a good use of position is to place the entry symbol for every EOP in a consistent location either at the top center of the flowchart sheet or at the top left, as shown in Figure 5.9.

The need for consistency in positioning elements of a graphic representation is recognized in the magazine industry. A standard technique in that industry is to design the layout of all "spreads" (sets of facing pages) so that they form a visual unit. All of the spreads should appear to belong together. However, it is also realized that the magazine will be visually boring if each spread is set up with identical arrangements of text columns and pictures. To address these concerns, magazine designers frequently employ grids to design page spreads. The placement of text columns and pictures is then dictated by the grid. The grid gives the designer a fair amount of flexibility to produce varied and visually appealing layouts, but the designer is sufficiently restricted by the grid to produce only layouts that are visually tied to the other layouts in the magazine. The purpose of the grid system is to force order into the creative process of layout design. Designers of flowchart EOPs may find that following such a grid system promotes consistent visual patterns in flowcharts as well. A very simple flowchart grid system, taken from Shelly and Cashman (1972), is shown in Figure 5.10.

5.3.2 Implied Movement

In flowcharts, a sense of implied movement is created through position variation, and the use of flowlines and connector symbols. The primary factor that determines implied movement in flowcharts is the flowlines (or, in the case of transitions, connector symbols), because these dictate the path the operator must follow through the chart. The sense of implied movement is reinforced by the position of the symbols in the flowchart. In fact, if an operator looks at a flowchart quickly or from a distance, the flowlines will not be obvious and the sense of implied movement will be created entirely by the placement of symbols. If the symbols in the flowchart are not arranged in a logical, ordered fashion (e.g., in columns), the sense of implied movement is obscured.

Dondis (1973) explains that up to three different forces can simultaneously influence how a viewer's eye moves through a graphic presentation: (1) the eye moves according to each individual's personal scanning patterns, (2) the eye moves as it is led by the graphic cues in the presentation, and (3) the eye follows a left-to-right and top-to-bottom pattern. Although the

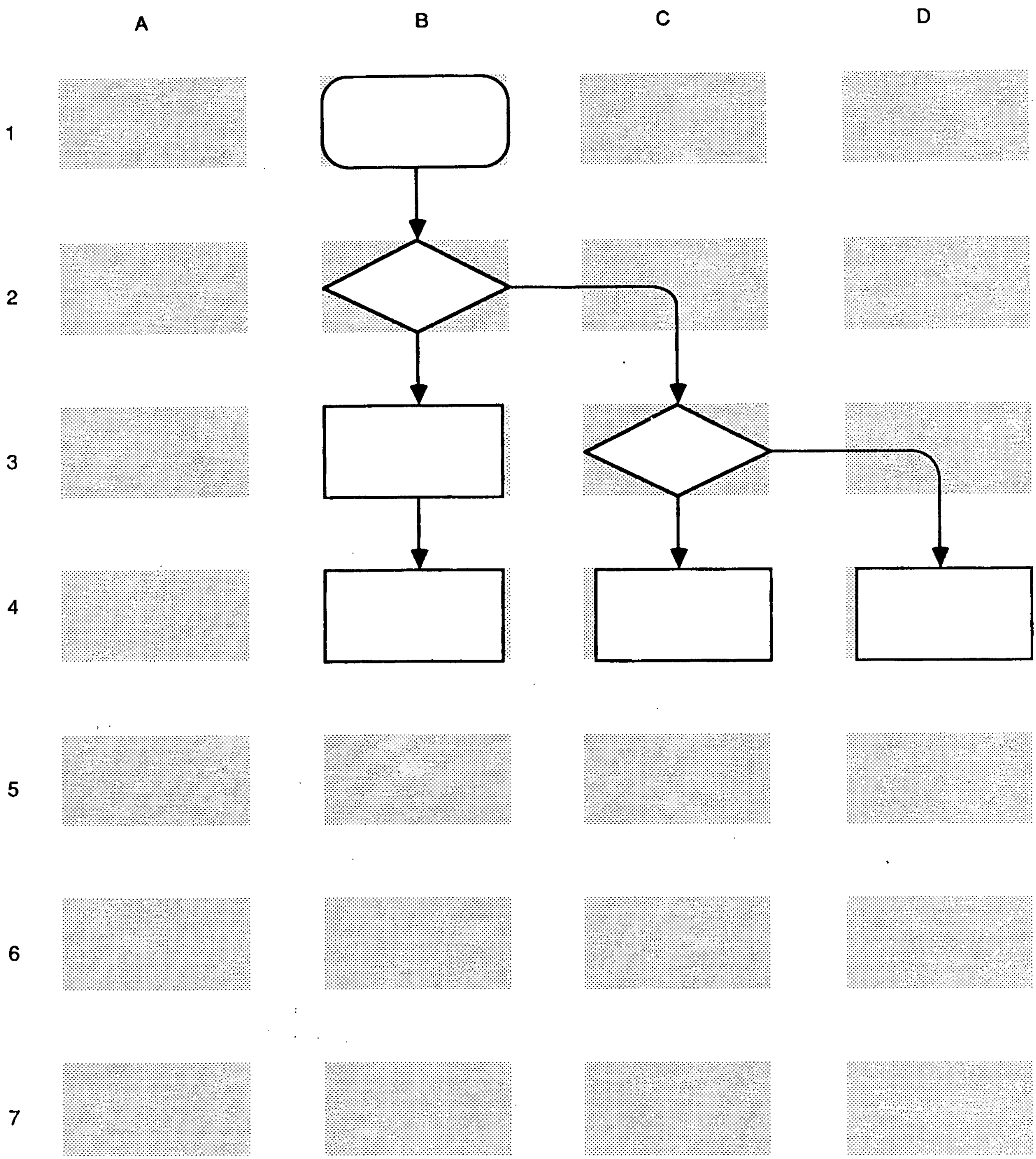


FIGURE 5.10. A Simple Flowchart Grid System

flowchart designer can do little about each individual's personal scanning pattern, he or she can position items to take advantage of the viewers' natural left-to-right, top-to-bottom scanning pattern, and create graphic cues that direct the eye correctly (ANSI, X3.5-1970). These graphic cues include arrows on flowlines, curving the turns in flowlines, merging adjacent parallel flowlines, using different line types carefully, and using connector symbols to avoid crossing flowlines. Each of these techniques for guiding movement through flowchart EOPs is discussed below.

5.3.2.1 Left-to-Right, Top-to-Bottom Reading Patterns

The tendency for people to read a graphic from left-to-right and from top-to-bottom can be a stronger force than the movement cues created by other graphic variations, such as the construction of flowlines with arrows. Winn and Holiday (1982) describe an experiment that demonstrates that

> ...students "read" diagrams from left-to-right and from top-to-bottom, just as they read prose, and...that the usual techniques for showing direction, such as arrows, are not sufficiently strong enough to override the conventional way of reading information. (p. 289)

Winn and Holiday attempted to teach students the evolutionary sequence of dinosaurs. One group of students was given a diagram that showed the evolutionary sequence from left (oldest) to right (most recent). Another group was given a reversed image that showed the oldest dinosaurs on the right and the most recent dinosaurs on the left. In both diagrams the sequences were reinforced by arrows and by pictures of dinosaurs that faced in the direction of the arrows (from oldest to most recent). The reversed diagram proved substantially inferior to the left-to-right oriented diagram:

> Those who saw the first diagram were far more successful in learning this [the evolutionary sequence] than those who saw the diagram where the sequence had been reversed. In fact, learning from the reversed diagram proved to be so difficult that the students performed no better on the test than students in a control group, who had been given no diagrams and no information about the evolutionary sequence at all...the reversed-diagram group had learned virtually nothing about the sequence. (pp. 286-287)

In a flowchart that violates the left-to-right, top-to-bottom conventions, it is possible that operators will follow the natural tendency to read left-to-right (or top-to-bottom) in spite of arrows that indicate a contrary flow of movement. In addition, if an operator is quickly skimming through a flowchart to get a general overview of the procedure, flowlines that flow right-to-left or bottom-to-top may be disruptive and confusing. Although an operator may be able to follow a single right-to-left flowline while executing a procedure, it would be difficult for him to ignore several such lines while overviewing a flowchart. Therefore, EOP flowpaths should be structured to encourage top-to-bottom and left-to-right reading patterns.

5.3.2.2 Arrows on Flowlines

Arrows drawn along flowpaths enhance the directional information provided by lines. Arrows are very strong graphic cues. According to Bailey (1982), an arrow indicating movement is one of the most easily interpreted symbols available to the graphics designer. Well-designed flowlines containing arrows have an obvious and immediate meaning that is not easily ignored, that is, they have a dissociative nature.

Collins and Lerner (1982) evaluated proposed fire-safety symbols by testing subjects' abilities to understand the meanings of various symbols. Symbols that included arrows were tested, and then the arrow was tested in isolation to determine if it conveyed a meaning in and of itself which confused the meaning of the symbols that contained arrows. The arrow in isolation conveyed the idea of "exit," "one way," or "go this way" to 82% of the subjects. Of the various exit symbols examined by Collins and Lerner, the one symbol that used an arrow to augment the symbol's meaning was determined to be the most effective.

A flowchart designer interviewed for this report encountered a problem where the strong impact of an arrow obscured the meaning of a symbol containing the arrow. The interviewee had constructed a flowchart that included a special symbol for override steps. The symbol included a bracket that surrounded the steps which could be overridden. An arrow was placed at the end of this bracket. Operators complained that even though they knew what the symbol meant, the combination of the line (created by the bracket) and the arrow made them want to follow the bracket as if it were a flowline. When they encountered the override step, the first reaction operators had was to follow the bracket to the arrow and proceed with the step that the arrow seemed to point towards, ignoring the other important steps in the sequence. Operators had such a difficult time attempting to overcome this tendency that it was necessary to remove the arrow from the symbol.

5.3.2.3 Turns in Flowlines

Changes in the direction of flowlines should be kept to a minimum (Chapin, 1974). According to Bertin (1981) flowcharts are often complex in themselves so it is necessary to eliminate all needless complexities in layout, such as needless turning of lines. Bertin (1983) also states that any angle destroys the unity of a line: a flowline will more clearly show direction if the entire length of the line points in one direction.

Turns in flowlines can lead to errors when operators attempt to follow the lines. For example, Figure 5.11 shows flowlines with unnecessary angles. An operator following such lines could easily make the mistake of moving from point A to point D, rather than moving to point B. Note that it would be especially easy to make such an error if the flowlines were made up of dashes rather than solid lines.

Richards and Johnson (1980) recommend using curves rather than angles when flowlines change direction, and having flowlines meet tangentially, as shown in Figure 5.12. These curved lines direct the eye through the change in

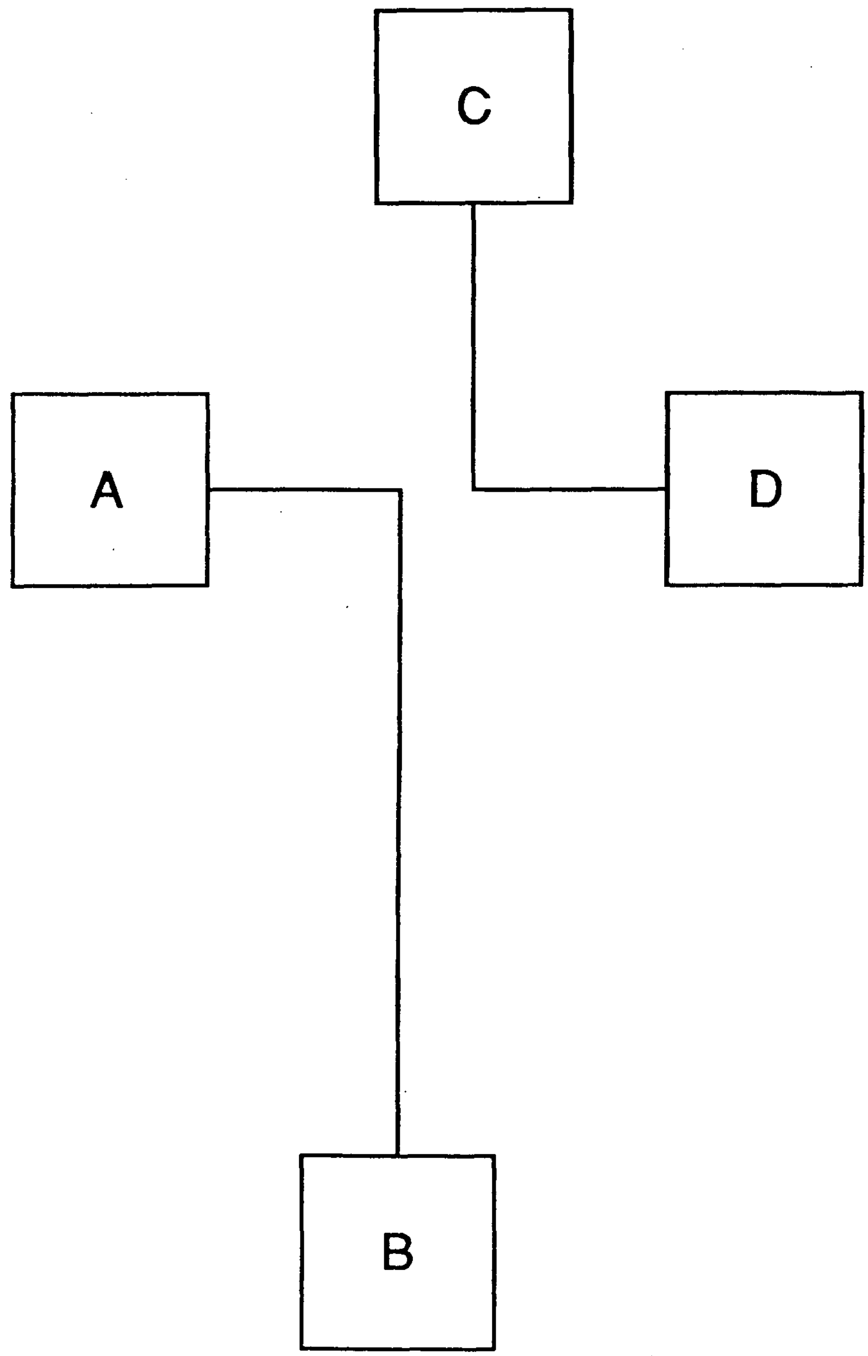


FIGURE 5.11. Confusing Arrangement of Flowlines

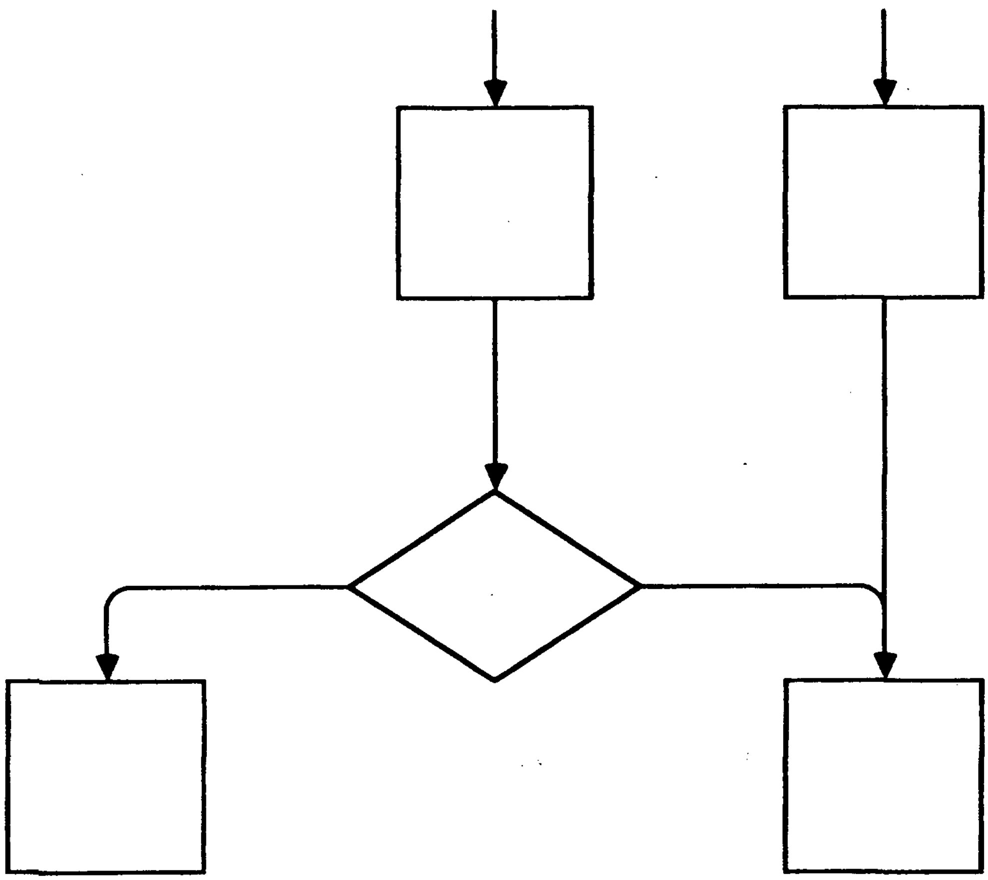


FIGURE 5.12. Flowlines That Meet Tangentially

direction, and make it more difficult to follow a flowline in the wrong direction. When flowlines meet, the curved line implies an arrow that points out the correct direction of movement.

5.3.2.4 Adjacent Parallel Flowlines

Closely-spaced parallel lines can be especially confusing in flowcharts (Chapin, 1974). The principle concern with parallel flowlines is that operators could follow the wrong line by mistake, and proceed through the flowchart along the wrong path. Additionally, closely-spaced parallel lines prevent the graphics of the flowchart from showing the organization of the procedure clearly. These problems are especially pronounced when the flowlines are long, such as lines that go from the bottom of the flowchart sheet to the top of an adjacent column on the sheet.

If lines are closely spaced because several lines flow to the same location, the best solution is to eliminate some of the lines. Several of the flowchart EOPs examined contained parallel lines that all ended at the same symbol in the flowchart. These lines not only ran parallel to each other, but they ran parallel to other flowlines that ended in different symbols as well. Figure 5.13 demonstrates how these lines can be hard to follow and how they are visually confusing. Figure 5.14 shows the benefits of merging closely-spaced parallel lines. In Figure 5.14, a single vertical line replaces the three parallel flowlines in Figure 5.13. This format is less likely to cause errors and is visually less disturbing. Notice, however, that it is especially important that the merged flowlines in Figure 5.14 meet tangentially, or operators could make a "wrong turn" and follow a flowline in the wrong direction.

If the parallel flowlines occur coincidentally and do not end in the same symbol, then there is no reason that they should remain close to each other. Because the physical organization of the flowchart should reflect the logical organization of the procedure, these logically separate flowlines should be physically separated with additional white space.

5.3.2.5 Types of Lines

Different types of lines can be used in a flowchart to indicate substantial structural or organizational information. For example, a wide dark line marking the most critical flowpath would be apparent when a flowchart is overviewed. In using different types of lines, however, it is important to ensure that the different line types are readily perceived and easily interpretable.

Bertin (1983) demonstrates how different variables can be used to visually separate lines. Figure 5.15, based on Bertin's work, shows attempts to distinguish line segments by variations in position, size, value, texture, and shape. The textures used in this example also vary in value; the solid line being the darkest and the dotted line being the least dark. Note that position clearly and unambiguously separates the lines without imposing an ordered hierarchy on them. Size, value, and texture also separate the lines, but, because they are ordered variables, they impose an order on the sequence

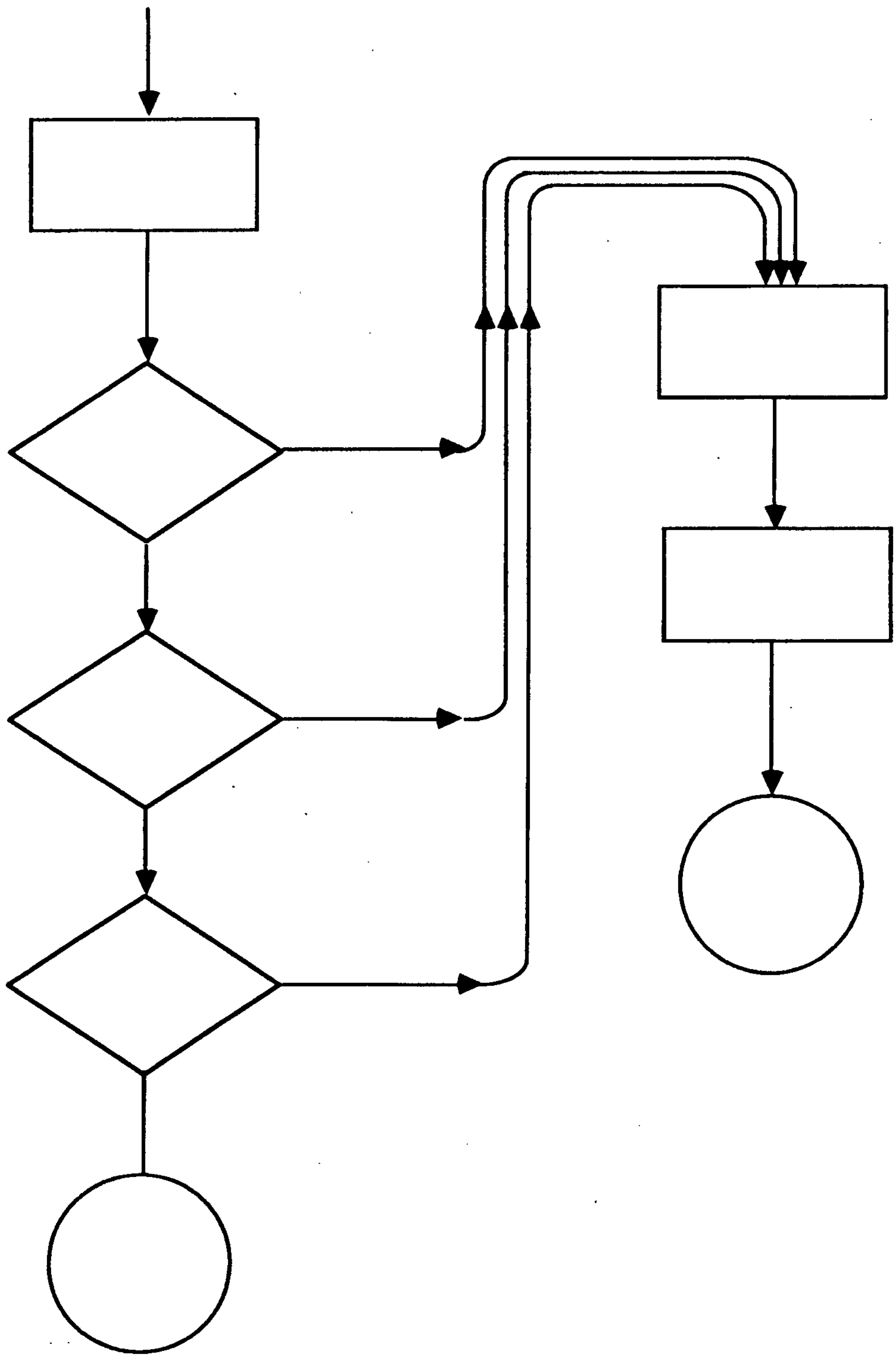


FIGURE 5.13. Parallel Flowlines

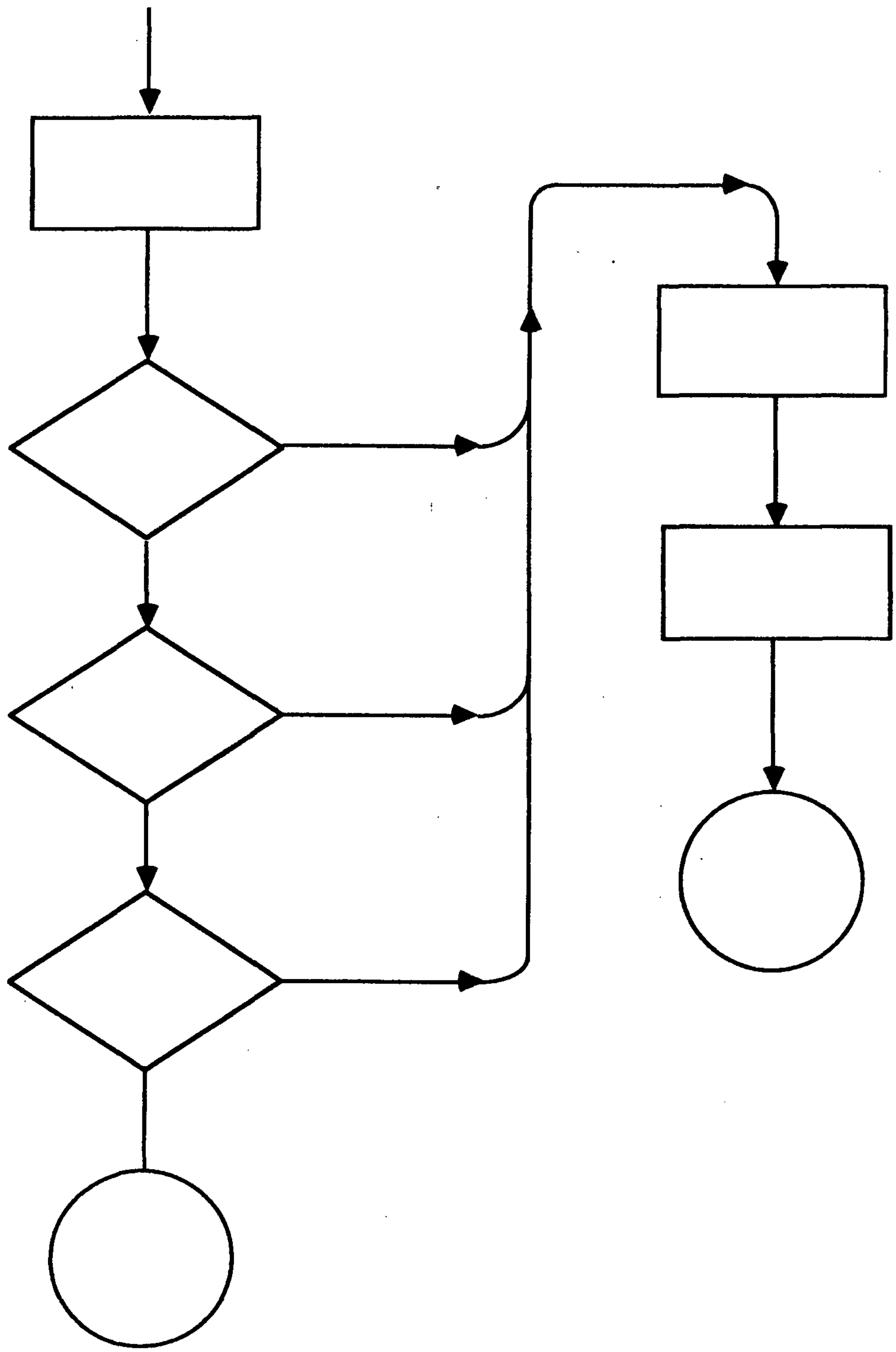


FIGURE 5.14. A Single Line Used to Replace Parallel Flowlines

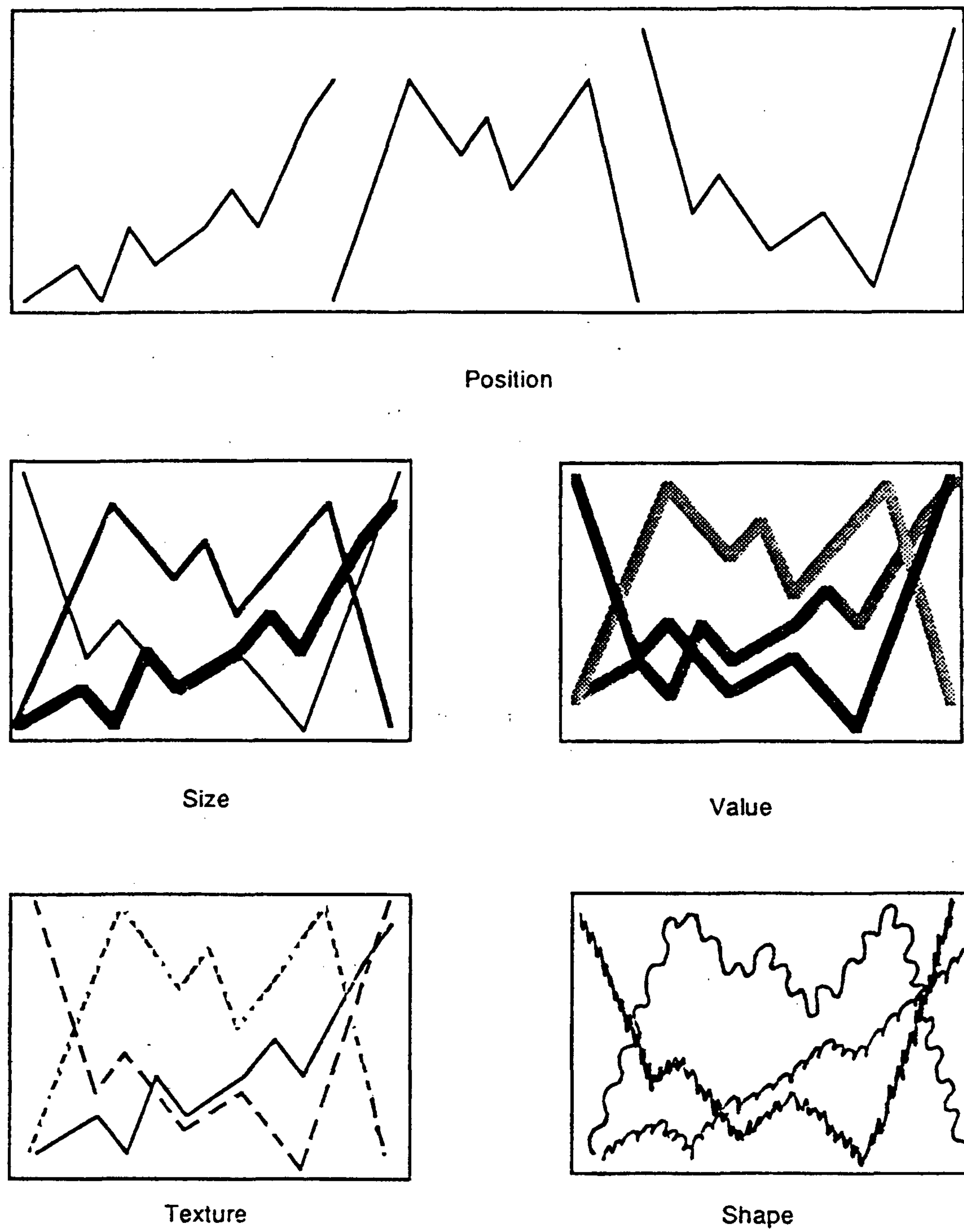


FIGURE 5.15. Line Segments Differentiated by Position, Size, Value, Texture, and Shape

Source: Adapted from Semiology of Graphics Diagrams Networks Maps (p. 68) by J. Bertin (W.J. Berg, Trans.), 1983. Madison: University of Wisconsin Press.

of lines--from widest to thinnest, from darkest to lightest, from most coarse (solid) to most fine (dotted)--that may be unwanted. Value and texture variation should be used sparingly for flowlines because light lines and lines with fine texture can be difficult to see. Shape fails to separate the lines and creates visual noise. Figure 5.15 shows that position is the best method for visually separating lines, although two levels of value can also be effective.

Color can also be used to differentiate flowlines without imposing an order on the lines, but special perceptual concerns must be considered when using color. Some color sequences can also be used to a limited degree when showing an ordered sequence of line types, if operators are sufficiently trained. (See Section 5.3.7 for details on color coding.)

5.3.2.6 Connector Symbols

Some problems of showing implied movement in flowcharts are caused by confusing juxtapositions of flowlines (e.g., the preceding example of closely spaced parallel flowlines). Sometimes confusion can be reduced by eliminating flowlines from the chart, and one way of removing flowlines is by using connector symbols.

A connector symbol is a special flowchart symbol that contains instructions for the operator to go to a position in the flowchart marked by a corresponding connector symbol. Connector symbols are always used in pairs; an exit connector symbol instructs the operator to leave a flowpath and go to another flowpath. An entry connector symbol identifies the point at which the operator should begin following the other flowpath. In flowcharts, connector symbols can be used to indicate referencing and branching, as shown in Figure 5.16.

Although the use of connector symbols can reduce the visual complexity of the flowchart, it disrupts the flow of information to the operators: after reaching an exit connector symbol, they must locate the corresponding entry connector symbol. To minimize the potential for placekeeping difficulties when connector symbols are used, the text within the exit symbol must provide the operator with precise information about where to find the entry symbol (Chapin, 1974). In addition, Chapin (1974) recommends that the borders of flowchart sheets be marked with grid letters and numbers so that entry connector symbols can be referenced by the row and column location (see Figure 5.16).

The problems inherent in the use of the connector symbol can also be reduced by marking the connector symbols with appropriate visual variables. To ensure that the symbols can be easily located, they could be marked with a selective variable. That is, the two connector symbols in a given pair of symbols could be linked by being marked with the same selective visual variable.

Considerable research has been conducted to determine what types of visual variations facilitate search processes, such as searching for an entry connector symbol. This research typically takes the form of testing the

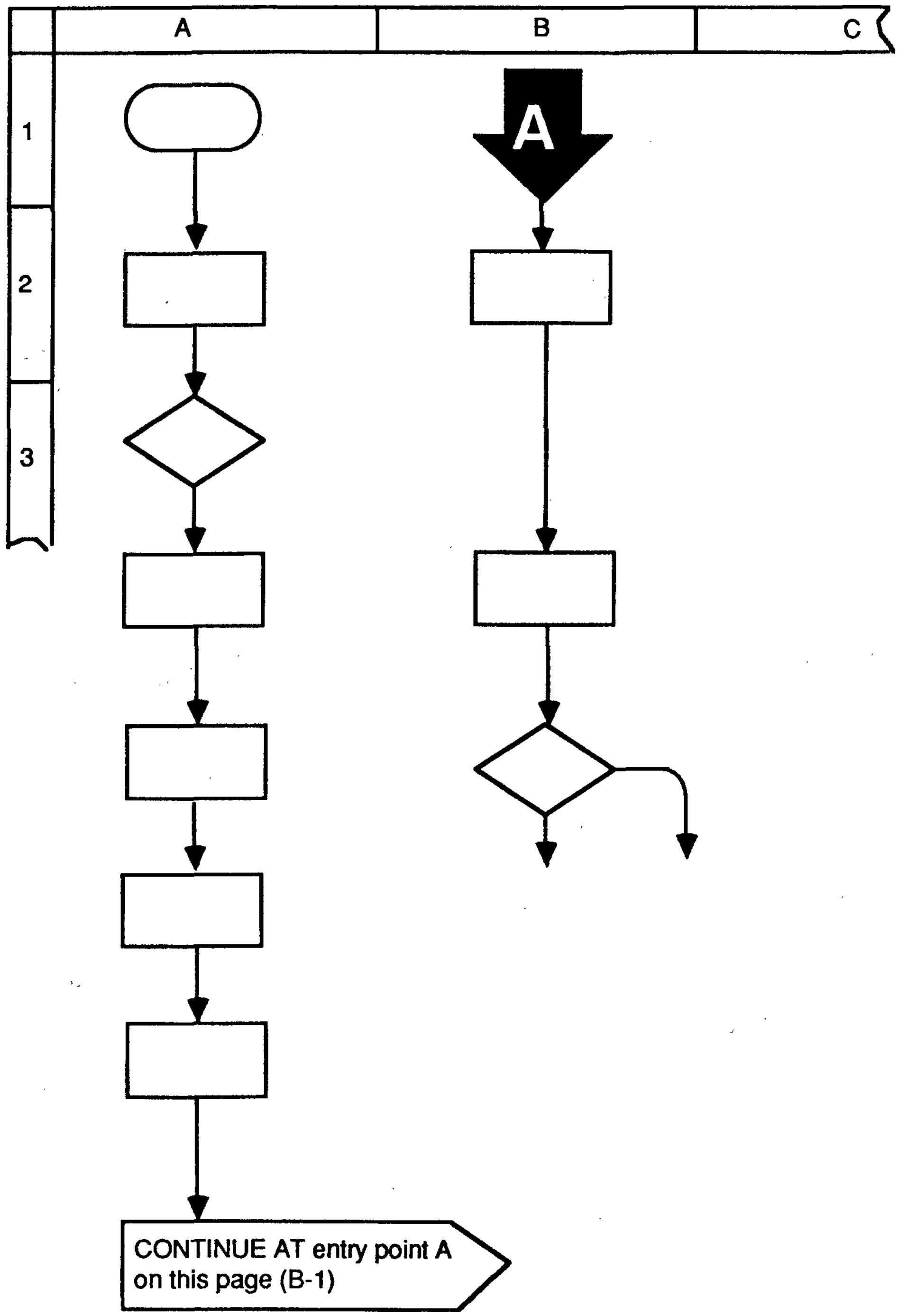


FIGURE 5.16. Connector Symbols Used to Indicate a Reference

speed and accuracy with which subjects can find a "target" image that is placed within a field of "distractor" images. Items in flowcharts for which operators must search, such as entry connector symbols, should have the properties of easily found targets. Familiar targets can be found more rapidly than less familiar targets (Wood, 1972), and the more the target contrasts with its environment the more easily it is found (Grether and Baker, 1972). Objects at the highest end of a given range (such as the largest, or those objects with greatest contrast with the background) have been shown to be the most easily found targets (Williams, 1973). Color has been demonstrated to be a better method of marking targets than is shape or size coding (Williams, 1973). However, because peripheral vision is fundamental to the search process, colors which are not identified well peripherally should not be used to mark targets. Green and red are the colors that are most difficult to discriminate peripherally.

To ensure that the sense of implied movement is disrupted as little as possible, the connector symbols should be marked with at least one dissociative variable. For example, if all entry connector symbols used in a flowchart are especially dark in value, as shown in Figure 5.16, they will stand out and be readily perceived by an operator attempting to find his next step. The use of letter codes can uniquely identify the members of each connector symbol set, as is also shown in Figure 5.16.

The absence of flowlines when connector symbols are used, however, in addition to making it harder to follow any given flowpath, also obscures the overall structure of the procedure. The strong associative tie of flowlines is lost. Thus, the use of connector symbols should be minimized.

5.3.2.7 Crossing of Flowlines

At times, it may be better to allow flowlines to cross than to disrupt a flowline with a connector symbol. For example, see Figures 5.17 and 5.18. There is no way to construct this flowchart so that the flowlines will not cross at some point. In such a situation, the symbol shown in Figure 5.18 is less disruptive of the sense of implied movement in the flowchart than is the connector symbols shown in Figure 5.17.

5.3.3 Shape

The primary use of shape variation in flowcharts is the design of flowchart symbols. Different symbol shapes can be assigned specific meanings that augment the meaning of the text presented within the symbols. Because shape variation is associative, using symbols of different shapes provides a cue to the meaning of the text in a flowpath without affecting the graphic unity of the flowpath.

Enclosing EOP text inside of symbols helps to ensure that the flowchart provides information about the organization of the procedure. According to Winn and Holiday (1982), placing text in symbols enhances the information conveyed through the spatial arrangements of the flowchart elements. The information presented within a symbol is tied together by the symbol and is distanced from information outside of the symbol. While position provides

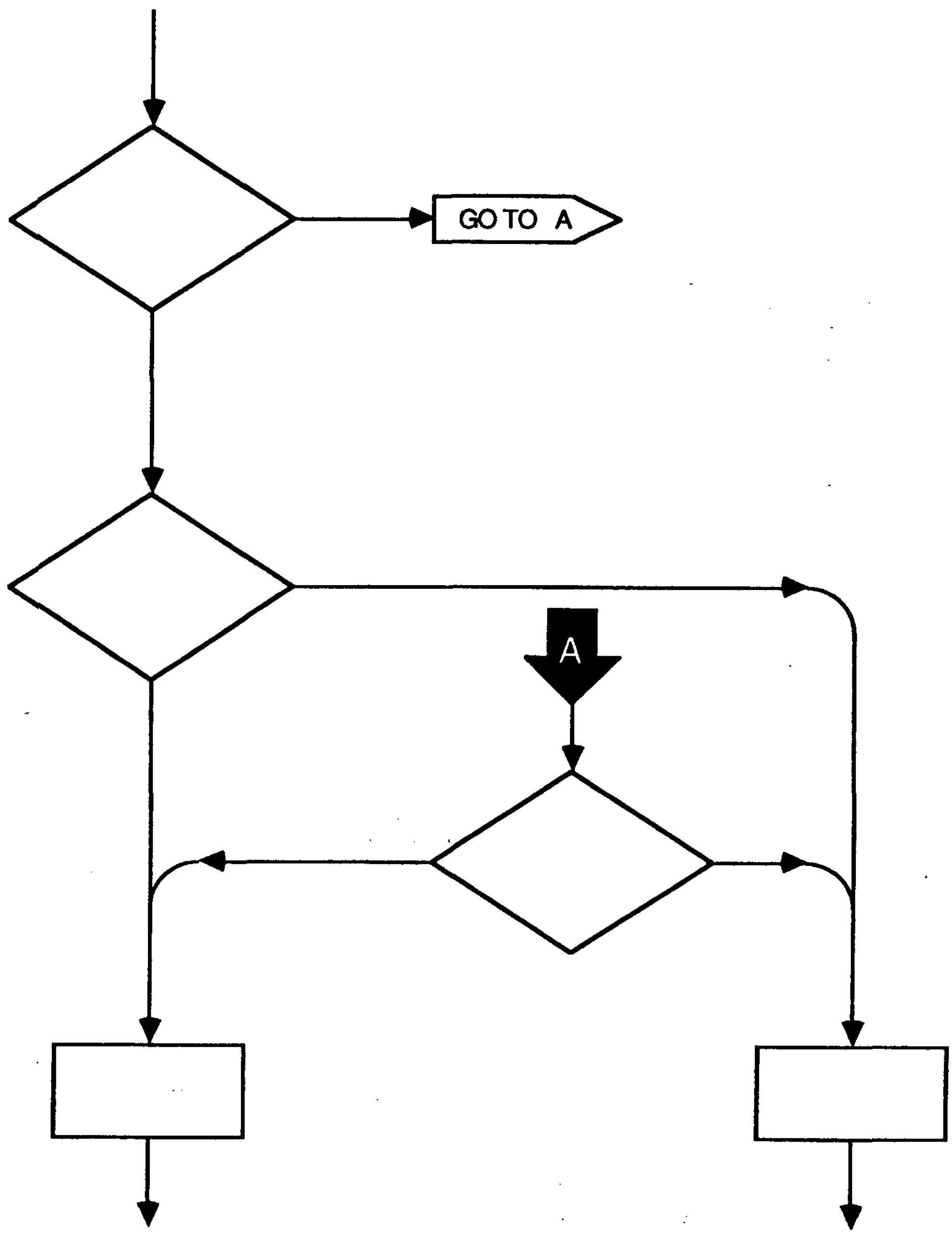


FIGURE 5.17. Connector Symbols Used to Avoid Crossing of Flowpaths

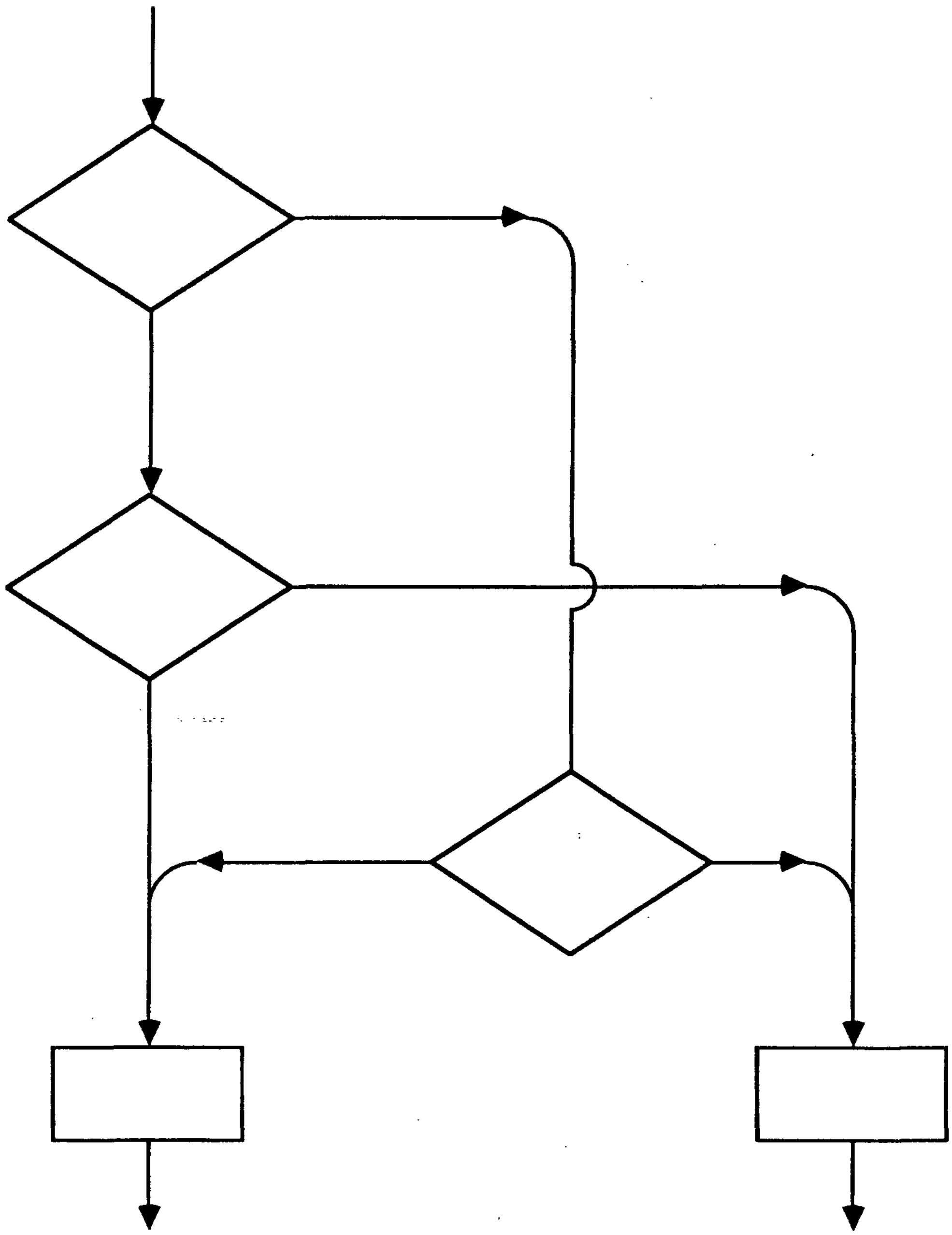


FIGURE 5.18. Crossing of Flowpaths

the initial and main cue about how the information contained in the text is related to other aspects of the flowchart, enclosing text in symbols reinforces this organizational information.

Because a wide range of flowchart symbols are possible, it is tempting to use shape variation extensively in the design of flowchart EOPs where there are many different types of action steps to present (see Section 6.4). However, the number of different symbols that can be used effectively in a set of flowcharts is limited (Richards and Johnson, 1980; Bailey, 1982). Standard conventions, practical considerations, and the operators' perceptions of the symbols in the context of an EOP should all be considered when designing or selecting a set of flowchart symbols.

The bulk of standard flowchart symbols have been developed for use in the computer industry, and therefore have a limited application to flowchart EOPs. However, some of the symbols, such as diamond-shaped decision symbols and rectangular action symbols, are frequently used in flowchart-format procedures. The American National Standards Institute (ANSI, X3.5-1970) has issued a report on standard flowcharting symbols and their uses for designing computer flowcharts. The symbols prescribed by ANSI are very similar to the symbols recommended by other authorities, such as IBM (Gleim, 1970). If operators at a particular plant are familiar with them, standard symbols such as decision diamonds and rectangular action steps are likely to simplify the use of flowchart EOPs.

Because EOPs differ significantly from computer programs, however, flowchart EOP designers may be required to develop some unique symbols. Our examination of flowchart EOPs revealed several non-standard symbols that appear to be effective. For example, an octagon, as in a stop sign, has been used as the symbol for hold points in EOPs. The text within the octagon includes a <u>WHEN</u>,...<u>THEN</u> statement that tells the operators to stop executing the procedure until certain conditions have been met. The stop sign symbol has the advantages that it is visually simple and has a familiar, relevant meaning.

Flowchart EOP designers may also choose to develop a symbol other than the diamond to signify decision points in EOPs. Richards and Johnson (1980) note that fitting text into the diamond-shaped decision symbol is especially difficult. Flowchart designers interviewed for this project stated that the problem is particularly pronounced when a decision requires a long question: if the symbol must be enlarged to accommodate a long block of text, a significant amount of space is wasted.

Alternatives to the diamond-shaped decision box, which allow for a more efficient use of space, have been used in various flowcharts. For example, Lane, Cronin, and Peirce (1983) used a variation of the rectangular action box as a decision symbol. The decision symbol is differentiated from action symbols by the use of shading along two sides of the decision symbol, creating the appearance that the symbol is casting a shadow onto the page (see Figure 5.19). This decision symbol solves the problem of efficiently placing text within decision symbols, but the symbol is not well-differentiated from action symbols.

Another possible shape for a decision symbol is a rectangle with the corners of the diamond shape placed along its borders, as shown in Figure 5.20. The corners of the rectangle are rounded so that the only sharp angles in the symbol are the angles of the diamond shape. This symbol uses space almost as efficiently as the simple rectangle, is clearly different in appearance from the rectangular action symbol, and preserves all of the angles that contribute to the recognizability of the traditional diamond-shaped decision symbol.

The psychological connotations created by different shapes should be considered by the flowchart designer when developing non-standard flowchart symbols. Dondis (1973) describes three basic shapes and attributes specific meanings to each of these shapes. The three basic shapes are the circle, the square, and the equilateral triangle. The conventional meanings associated with these shapes are as follows: "The square has associated to it dullness, honesty, straightness, and a workmanlike meaning; the triangle, action, conflict, tension; the circle, endlessness, warmth, protection" (p. 44). Dondis (1973) states, "Curved directional forces have meanings associated with encompassment, repetition, and warmth" (pp. 46-47). These meanings generalize to other figures derived from the basic shapes. That is, ovals will convey meanings similar to the meanings conveyed by circles. Rectangles and parallelograms will convey meanings similar to squares, while other triangles and diamonds will convey meanings similar to the meanings conveyed by the equilateral triangle.

Note that these attributes of shapes are generally used well in standard flowchart symbols. The rectangle, a variation of the square that has a "workmanlike meaning," is used for action steps, which direct the actual work of the operators. The diamond shape, with angular properties like the triangle, is used for decision steps. This capitalizes on the sense of conflict conveyed by the triangle. The circle, which conveys endlessness and encompassment, is used as an entry symbol and a connector symbol in computer flowcharts.

It is also important that the symbols used in a flowchart EOP are easily distinguishable by operators. Experts using symbols in various contexts concur that the symbols in a set must be very different from each other to be readily and accurately perceived (Misra and Ramesh, 1969; Wood, 1972; Green and Pew, 1978). Augmenting shape variations with dissociative variations, such as variations in position, size, and value, is the best method of ensuring that specific symbols in flowcharts can be easily perceived by operators. One flowchart designer interviewed for this report used these variables to mark override steps very effectively. An example of the symbol used by this interviewee is shown in Figure 5.21. The symbol is substantially larger than other symbols in the flowchart. At the top of the symbol, a box extends horizontally over the portion of the flowchart containing the steps which may be over ridden. Lines extend down both sides of the step to form a frame around these steps. The lines which form the override step are wider, and therefore of a darker value, than the lines forming other steps in the flowchart. The large size and dark value of this symbol make it extremely easy to distinguish from other symbols, even in a complex flowchart. The position of the symbol makes it easy to determine the

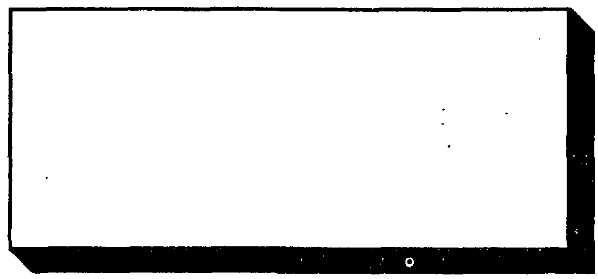


FIGURE 5.19. Shading Used to Show a Decision Symbol

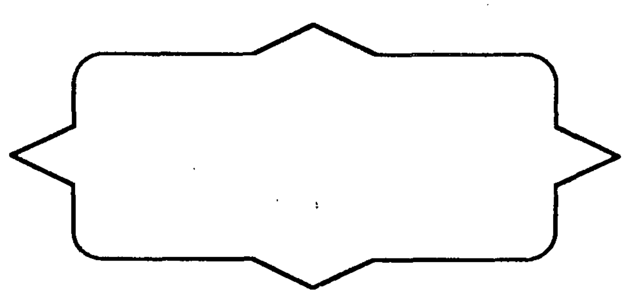


FIGURE 5.20. Diamond-Shaped Decision Symbol with Embedded Rectangle

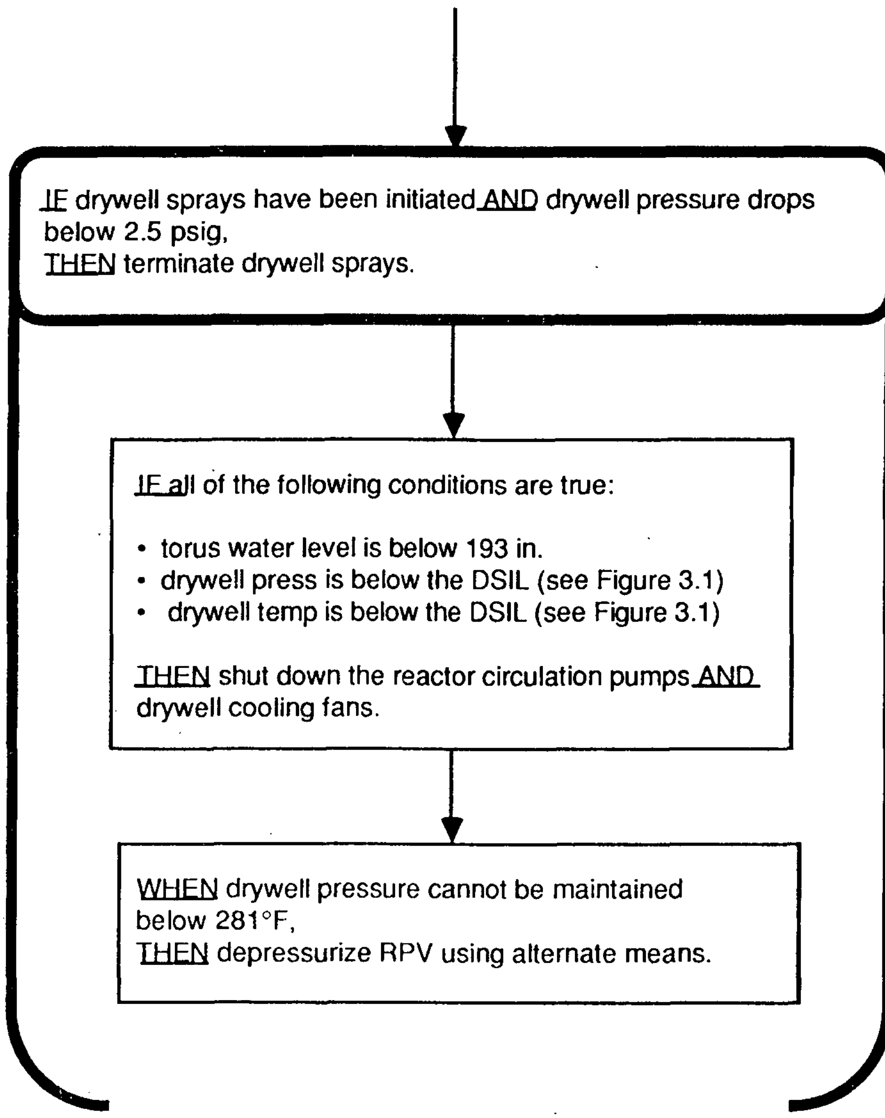


FIGURE 5.21. Override Symbol

steps to which it applies as the symbol literally surrounds the applicable steps.

The literature also suggests that the meanings that individual operators attach to symbols must be considered in selecting a flowchart symbol set (Cahill, 1975). According to Brandes (1976), it is widely accepted among academic cartographers that an examination of how users perceive symbols is the best means by which map designers should select symbols to use on maps. Collins and Lerner (1982) conclude that the understandability of any symbol set should be tested before the symbols are put into practice:

> In summary, the extreme range of understandability of the symbols investigated in this experiment indicates the need to test symbols before widespread adoption. The low level of meaningfulness and the potentially dangerous confusions produced by some symbols...is particularly troubling. As a result, it is necessary to incorporate testing procedures as integral parts of symbol development.... (p. 84)

For similar reasons, operators' interpretations of flowchart symbols should be tested by the flowchart designer before the symbols are used in flowchart EOPs.

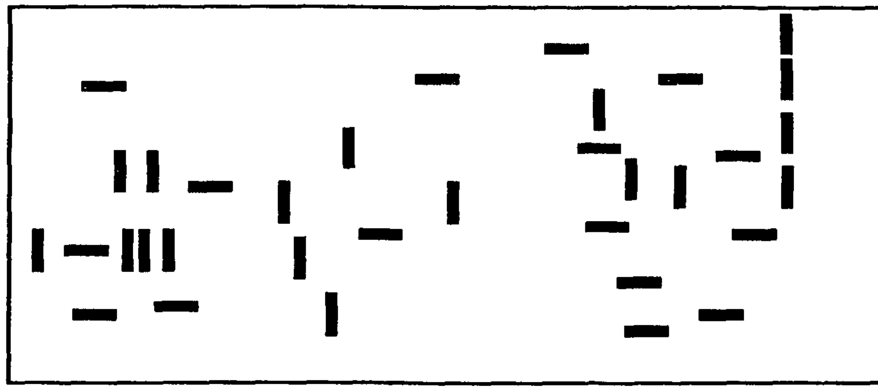
5.3.4 Orientation

Orientation is likely to be of limited use in flowchart EOPs. Orientation can be used to show associative and some selective relationships. Similar items can be associated together even if they have different orientations. For example, all rectangles in an flowchart can be associated together even if some of the rectangles have their longer side along the horizontal axis of the plane and others have their longer side along the vertical axis.

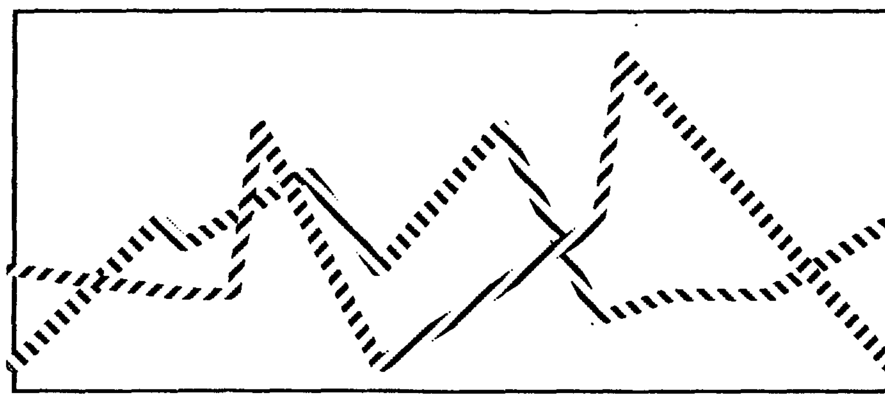
Orientation can also be used to show selective relationships to a limited degree. An item can be selected as belonging to the set of all items with a similar orientation. For example, a graphic representation could contain various shapes, including a rectangle that has its longest leg along the horizontal axis. This rectangle could be selected as belonging to the set of rectangles, and ovals that have a horizontal orientation.

Figure 5.22 illustrates how well orientation shows selective relationships for points, lines, and areas. Although orientation does allow fairly easy selection of lines and has some selective value for points, it is not effective for showing selective relationships for areas.

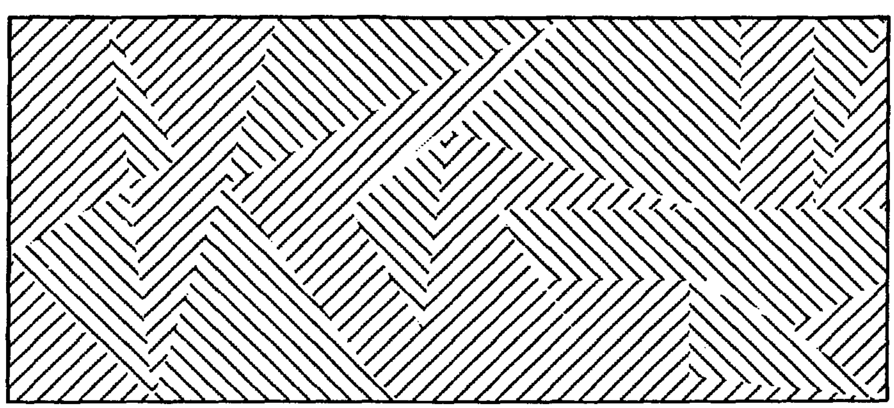
Orientation can be used in flowcharts to expand the size of the symbol set. For example, the square and diamond in Figure 5.23 are in fact the same shape, but the orientation of the figures differs by 45°. Symbols differentiated only by orientation may not be as readily distinguished as symbols differentiated by shape, however, especially if the flowchart is viewed at an angle.



Points



Lines



Areas

FIGURE 5.22. Use of Orientation to Show Selective Relationships for Points, Lines, and Areas

Source: Adapted from Semiology of Graphics Diagrams Networks Maps (p. 68) by J. Bertin (W.J. Berg, Trans.), 1983. Madison: University of Wisconsin Press.

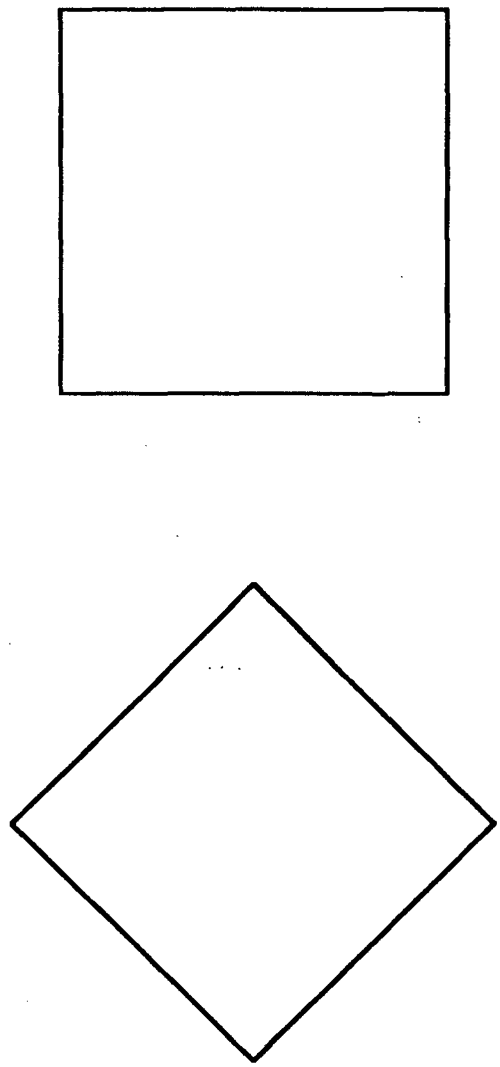


FIGURE 5.23. Orientation Used to Differentiate a Square from a Diamond

5.3.5 Size

The most significant aspect of size variation to the flowchart designer is that size has a dissociative nature. Consequently, special care must be used when size is manipulated in flowcharts. Changes in size are not easily ignored, and signal a change in meaning whether intended or not.

The dissociative nature of size can be capitalized upon in flowchart EOPs by using size as an emphasis technique. Large items will draw and hold attention and will be perceived to be more significant than smaller items (Hartman, 1961). For example, Figures 5.24 and 5.25 are identical in the arrangement of symbols and flowlines. However, the charts appear to have a different structure because of the change in the size of C.

The flowchart designer must ensure that changes in size do not provide false visual cues. To some extent, these false cues can be alleviated through careful use of position. In Figure 5.26, the position of the items in Figure 5.25 has been changed so that the structure of Figure 5.24 is more accurately shown. The parallel positioning of B and D in Figure 5.26 preserves the equality between them shown in Figure 5.24, although the larger size of C still suggests that it is more important than A, B, or D.

Size can also be used for showing selective relationships, such as variations in the sizes of flowlines. Showing ordered relationships is perhaps the most effective use of size: important items should be larger than minor items, primary actions should be larger than secondary actions. However, because size is ordered, an order will always be imposed on a sequence of items differentiated by size.

The usefulness of size variation is limited because of the limited range of sizes that can be used in a flowchart. Small objects must be clearly visible and large objects must not be so large that the entire flowchart becomes large and unwieldy, or crowded and hard to read.

5.3.6 Value

Value, also referred to as tone, is the ratio of black to white perceived on a surface. Value variations can be made in shades of grey or through any color. Value as a property of color is discussed in greater detail in Section 5.3.7.

Value variation is probably the most striking and powerful retinal variable available to the flowchart designer. As Dondis (1973) explains, value variation is a fundamental aspect of perception.

> Lightness and darkness are so intensely important to the perception of our environment that we accept a monochromatic representation of reality in the visual arts and we do it without hesitation. In fact, the varying tones of grey in photographs, film, television, etching, mezzotints, tonal sketches, are monochromatic surrogates and represent a world that does not exist, a visual world we accept only because of a dominance of tonal value in our perceptions. The

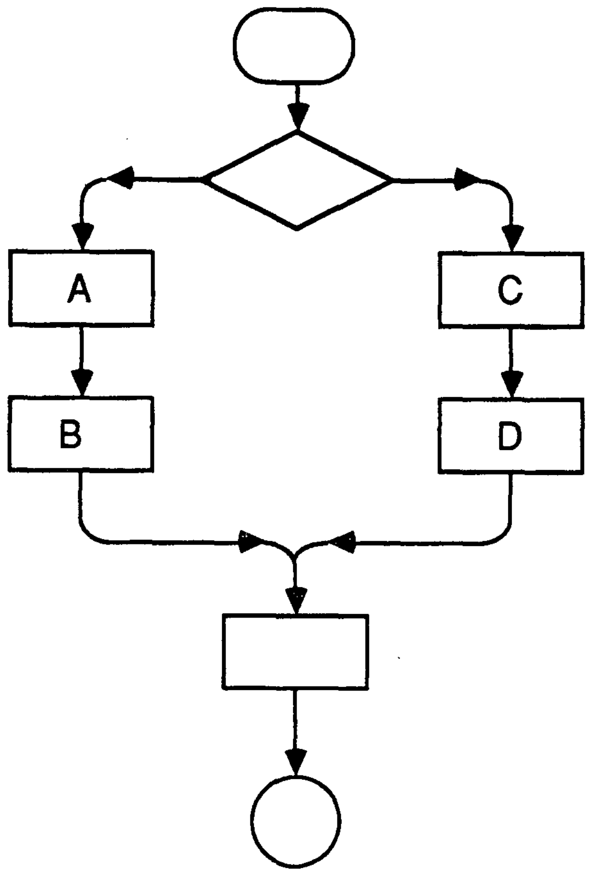


FIGURE 5.24. Horizontal Alignment Used to Show Relationships.

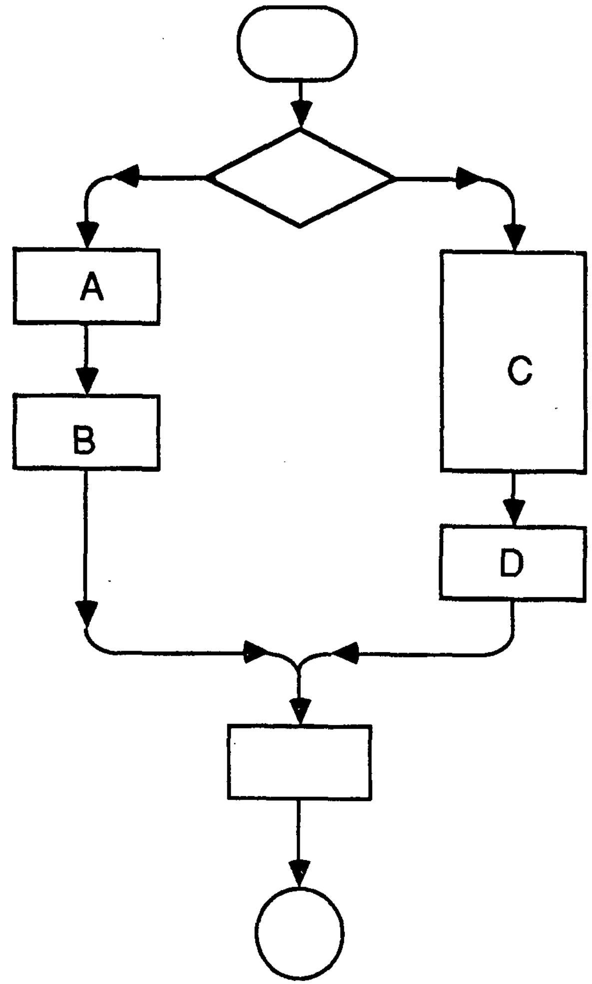


FIGURE 5.25. Horizontal Alignment Distorted by Size Variation

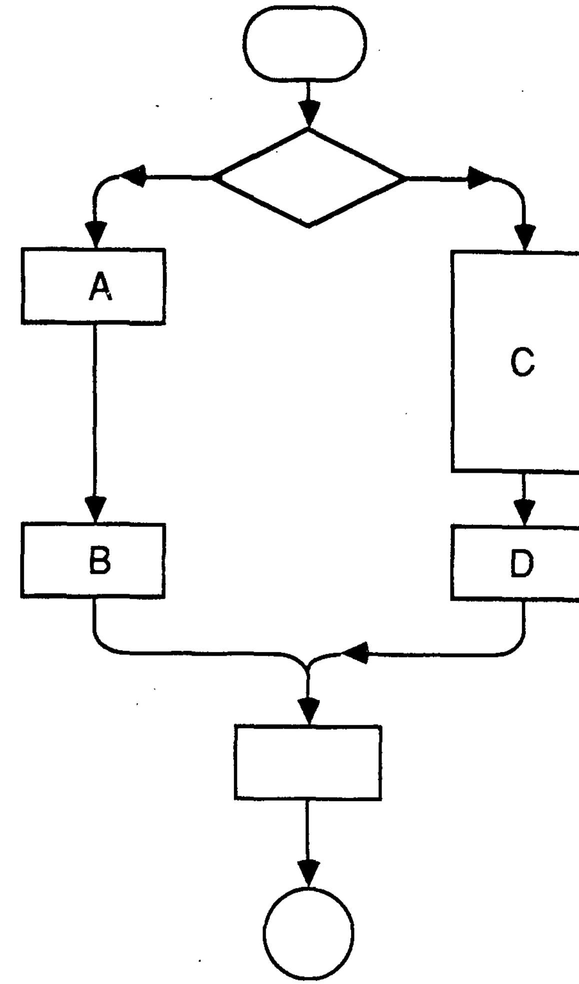


FIGURE 5.26. Vertical Spacing Used to Restore Horizontal Alignment

> ease with which we accept the monochromatic visual representation is the exact measure of just how vitally important tone is to us, and even more interesting, just how unconsciously sensitive we are to the dull, monochromatic values of our environment. How many people even realize they have this sensitivity? The reason for this startling visual fact is that tonal sensitivity is most basic to our survival. It is second only to the vertical-horizontal reference as visual clues to our relationship to our surroundings. Through it we see sudden movement, depth, distance, and other environmental references. Tonal value is another way of describing light. Through it and only through it, we see. (pp. 49-50)

Clearly value variation is extremely important in the design of flowcharts.

As previously noted, value variation is dissociative and ordered. Changes in value will always signal changes in meaning and will dominate over changes in other variables. The dissociative nature of value variation makes dark values a useful tool for marking items in flowcharts that are especially important for operators to see. Dark value is useful, for example, to mark steps of continuous applicability and cautions. Bertin (1983) stresses that value is ordered and that it cannot be reordered. Consequently, a dark area will inevitably be perceived as more important than a light area whether this message is intended or not.

The degree to which value variation can be used in flowcharts is limited by several factors. The steps between each value must be clearly identifiable, and the lightest value must be dark enough to be visible on a light background. With pale values, the identifiable number of sizes, shapes, colors, orientations, and textures diminishes and eventually disappears. Therefore, increasing the number of values used in a flowchart will diminish the number of different sizes, shapes, colors, orientations, and textures that can be used, because increasing the number of values will mean that paler values must be added.

In addition, visual density is a concern in flowcharts. Excessive use of dark values, especially dark areas, will make the flowcharts appear denser. Therefore, dark values should be used sparingly when dealing with areas. Examination of flowchart EOPs also revealed that wide (and therefore dark) flowlines compound the confusion generated by closely-spaced parallel flowlines. Care should also be taken when using dark values with any points used in flowcharts, although the concern here is less critical than for lines and areas, because points use less space on the flowchart.

Bertin (1983) advises that no more than six or seven levels of value (including black and white) be used for presenting selective information. However, because of the perceptual problems associated with very pale values, and the density problems associated with very dark values, value variation should probably be limited to even fewer levels in flowcharts. Four or five steps of value variation is probably a good maximum for flowchart EOPs.

5.3.7 Color

Used properly, color can be a powerful communication tool. Color can be used to draw and hold the viewer's attention and can be effectively combined with other visual variables such as size and shape (Bertin, 1983). This makes color useful for marking items for emphasis, and for marking target items. It may be especially useful in complex flowcharts, because additional information can be communicated through color while adding a minimal amount of extra visual noise to the flowchart. However, poorly used color can seriously impair communication. Overuse of color diminishes its usefulness and obscures other graphic cues.

5.3.7.1 Physical Properties of Color

There are three separate elements of color that can be varied to create different perceptions of color: hue, saturation, and value. Note that the principles of value variation discussed in Section 5.3.6 apply to value variation in any hue or in the black-to-white continuum.

Hue, the basic component of color, is a function of the wavelength of the light. Hue is the feature of visible light for which colors are named (e.g., blue, green, or yellow). There are three primary hues: yellow, red, and blue. All other hues can be created by mixing these three hues. There are also three secondary hues: orange (the mixture of yellow and red), purple (the mixture of red and blue), and green (the mixture of yellow and blue). Although hue perception varies among individuals, the following approximations show the generally accepted hues for speakers of American English: violet (380 nanometers to 450 nm), blue (450 to 480 nm), green (500 to 550 nm), yellow (570 to 580 nm) and red (610 to approximately 700 nm). The short wavelength hues are frequently referred to as being "cool colors" and the long wavelength hues are referred to as "warm colors."

Saturation (also referred to as intensity, brightness, or chroma), the purity of the color, is determined by the number of wavelengths (bandwidth) contributing to the color sensation. The narrower the band of wavelengths, the more saturated the color. Dondis (1973) describes saturated colors as being "simple, almost primitive,...both uncomplicated and overstated" (p. 51). The more saturated a color, the more it is perceived as bold and vivid. The less saturated a color, the more grey it appears, and the more it is perceived as subtle and restful. Saturated colors are rich and vibrant; unsaturated colors are pastel.

Value (also referred to as tone), the lightness or darkness of a perceived color, is also fundamental to the visual effect of a color. Value affects the perception of color, but operates independently from saturation and hue. A value continuum from white to black can be constructed in any hue at any level of saturation. Such a continuum can also be constructed in the complete absence of hue, purely in shades of grey.

Hue, saturation, and value are not just physical properties of light. The ways in which colors are perceived also depend upon a variety of physical, physiological, and psychological factors that must be considered when color is used as a communication tool. For example, Murch (1985) points out that hue is a function of the wavelength of light, but that it is primarily a perceptual phenomenon rather than a physical phenomenon. "Although people with normal color vision will name a sector of the spectrum as red, disagreement will occur about the reddest red or where red becomes orange. Such disagreement reflects varying experiences with color as well as the intrinsic differences in the color mechanism of each person's visual system" (p. 17).

5.3.7.2 Distinguishing Colors

There are two fundamental requirements for colors to be distinguished accurately. The colors must be accurately perceived, and the colors must be distinctly different from each other.

Not all colors are equally visible in all applications, and, in some applications, no combination of colors works as well as the combination of black and white. Because one of the bases of visual perception is value variation, color combinations where high contrasts of value exist can be used to ensure that an image is highly visible. One of the strongest contrasts available to the flowchart designer is black on white. Additionally, people are used to, and comfortable with, reading black text against a white background. This pattern should be the basis of the flowchart, and color should be used sparingly to provide additional graphic cues.

Greater contrast is created, and therefore colors can be more easily distinguished, if the color's values as well as hues are varied (Bertin 1981, 1983). Value variation allows for the selection of colors that stand out best at each value range. According to Bertin (1983),

> ...with light values, steps should be chosen around yellow, that is, from green to orange; blue, violet, purple, and red at light value are grayish and not very selective. Medium values offer the greatest number of selective color steps. The two saturated colors--blue and red--are diametrically opposed on the color circle, and the "grayish" sectors are reduced to a minimum. When dark values are being used, the best colors for making the marks stand out well run from blue to red (through violet and purple). Dark green, dark yellow, and dark orange are dull and not highly differentiated. (p. 87)

Some colors are not perceived well peripherally. Bailey (1982) explains that the area where color is perceived extends for about 60° on either side of a fixed point when the eyes are motionless. Color perception occurs from 30° above and 40° below the horizontal line of vision. With the eyes motionless, blue can be recognized at about 60°, with the colors yellow, red, and green recognizable closer to the fixation point. Because of this property of the human eye, Murch (1985) recommends that red and green should not be used at the peripheries of large displays, such as large flowchart sheets.

5.3.7.3 Using Color to Convey Information in Flowcharts

Color can be used to convey associative, dissociative, ordered, and selective information in flowcharts. Color variation may be either associative or dissociative, depending upon whether or not the values of the colors are varied. As is discussed below, color can be used to show ordered relationships, but special care must be taken when selecting color sequences for ordered relationships. Color can effectively convey selective relationships, but only if the colors used are clearly distinct from each other.

According to Bertin (1981, 1983), color variation is associative only if the values of the different colors used are not varied. Therefore, different items along a flowpath can be coded with different colors without obscuring the overall structure of the flowchart, provided that the value variation in the colors is not too great.

Value variation, however, is dissociative. As a dissociative variable, the changes in value may dominate the flowchart or distort relationships among flowchart elements. Items of equally dark colors on different flowlines may appear to be inappropriately closely related. Substantial changes of value between related items may place inappropriate visual distance between them.

Color variation has a limited ability to show ordered relationships. However, value variation is naturally ordered from dark to light or from light to dark. Therefore, a sequence of colors will convey an ordered sequence if the values of the colors vary. For this reason, Bertin (1981, 1983) explains that there are two possible hue sequences that can be used to show ordered relationships. Both of these sequences follow the color spectrum (violet, blue, green, yellow, orange, red) but each only uses half of the spectrum. Either the cool series, blue-green-yellow, or the warm series, yellow-orange-red, can be used, but both cannot be used well, nor can a range of the spectrum that does not place yellow at one end of the series be used. Attempts to use the total hue scale will not produce a clear ordered sequence. The problem arises because yellow and, to a lesser degree, the hues on both sides of it appear light in value. Because value is dissociative and naturally ordered, these light hues will appear to stand out and to belong to one end of the series or the other (Robinson, 1969).

Color can convey selective information, provided that the colors used contrast with each other adequately. Colors will be more easily distinguished if they vary in both hue and value; saturation variation should be limited. According to Bertin (1981, 1983), color selectivity is at a maximum near the saturated color and diminishes as one moves away from it. Saturated colors may be useful, then, for color coding pairs of connector symbols in flowcharts.

5.3.7.4 Limitations in the Use of Color

Many of the problems inherent in the use of color in graphic presentations are created or compounded by the excessive use of color. Additionally, overuse of color can interfere with achromatic elements of a graphic presentation. Hartley and Brunhill (1977) advise against the excessive use of color in educational materials:

> Using colour as a typographical cue is often unnecessary. Excessive use of colour can cause problems for the reader. Colour should be used sparingly and consistently, and its function explained to the learner. There is no need to use colour on every page simply because it is technically possible to do so. No colour has the contrast value of black on white. (p. 71)

Additionally, there are a variety of perceptual concerns that must be considered when using color. Prolonged viewing of an image can cause perceptual illusions and distortions. The more color is used, and the more varieties of color used, the more pronounced the perceptual distortions and illusions created by the use of color are apt to be. For example, saturation perception is distorted by prolonged viewing, such that colors appear less saturated after continuous viewing (Murch, 1985).

The context in which color is used can also affect the way colors are perceived. The interactions of colors with each other and with other elements in a graphic presentation can cause the colors to seem to shift in hue, saturation, and value. Colors maintain their hues, levels of saturation, and values only in isolation. When presented in juxtaposition with other colors, they tend to lose these characteristics (Wood, 1968; Misra and Ramesh, 1969; Murch, 1985).

Robinson (1969) discusses these perceptual problems and proposes some techniques for minimizing them:

> Another characteristic of vision and its relation to color in general, which the cartographer must bear in mind, is a general phenomenon called simultaneous contrast. If value is contrasted, simultaneous contrast can be especially problematic. The basic generalization is that any color characteristic is markedly modified by its environment. With respect to value, a dark area next to a light area will make the dark appear darker and the light appear lighter. This specific effect, called induction, makes it difficult for a reader to recognize a given value in various parts of a map when it is surrounded by or is adjacent to different values.... The effects of induction may be largely removed by separating adjacent values with a white space or by outlining areas with black lines. (p. 257)

Color is most effective when used to mark large areas, rather than for details such as small symbols, thin lines, and text. Color discrimination diminishes markedly when the size of the colored area diminishes (Wood, 1968;

Bertin, 1983). Bertin notes objects of less than 1.5 millimeter in diameter cannot support even a few different colors adequately.

Some colors are especially ineffective for varying lines and small areas. For example, Murch (1985) recommends that blue never be used for detailed images because the human eye is not designed to process detailed images in short wavelengths. When thin lines are used on a white background, there is a tendency for all hues other than bright red or yellow to be perceived as black (Wood, 1968). Yellow on white should not be used for thin lines (or any other details) because this combination provides very low contrast and is, therefore, hard to see (Turnbull and Baird, 1980). This leaves only bright red and black as good color choices for flowlines, which are in fact the conventional colors for showing lines on maps (Raisz, 1962).

In summary, color perception is a function of the environment in which the color is viewed, the length of time a color has been viewed, and the size of the colored object on the visual plane. Consequently, it is nearly impossible to guarantee that colors in flowcharts will always be perceived accurately. Color coding, therefore, should not be relied upon as the only means of presenting a particular type of information in a flowchart. Bailey (1982) strongly recommends that color coding should not be used alone or even as the primary means of providing information. Color variation should only be used in flowcharts to emphasize distinctions already made through another visual variable or through text.

5.3.8 Texture

Texture is the density and pattern of shading in an image (Bertin, 1983). Texture variation can be used to show associative, selective, and ordered relationships. Texture variation is very prone to creating visual noise, however, so its use should be minimized or avoided. Moire' type vibratory effects are especially problematic.

Like any sensory cells, the photoreceptors in the eye will suffer visual fatigue if they receive continuous uninterrupted stimulation (Gregory, 1970). This fatigue would cause viewed images to fade, if the eye were not adapted to dealing with this fatigue. The adaptation that prevents such fading of images is the tendency of the eye to make very small and rapid movements, which cause the light from images to strike different photoreceptors in the eye. Although these movements help prevent fatigue of individual photoreceptors, they also cause certain textures to appear to shimmer and move. This illusion of movement, called moire' vibration, is often used in op art. Figure 5.27 shows an example of moire' vibrations. Such patterns should not be allowed in flowcharts. As Tufte (1983) states, moire' patterns impede communication.

The vibratory effect of texture is most pronounced when areas are textured, but such problems also occur when lines are textured. For example, a flowchart constructed with dashed flowlines will have a busier appearance than a flowchart constructed with solid flowlines.

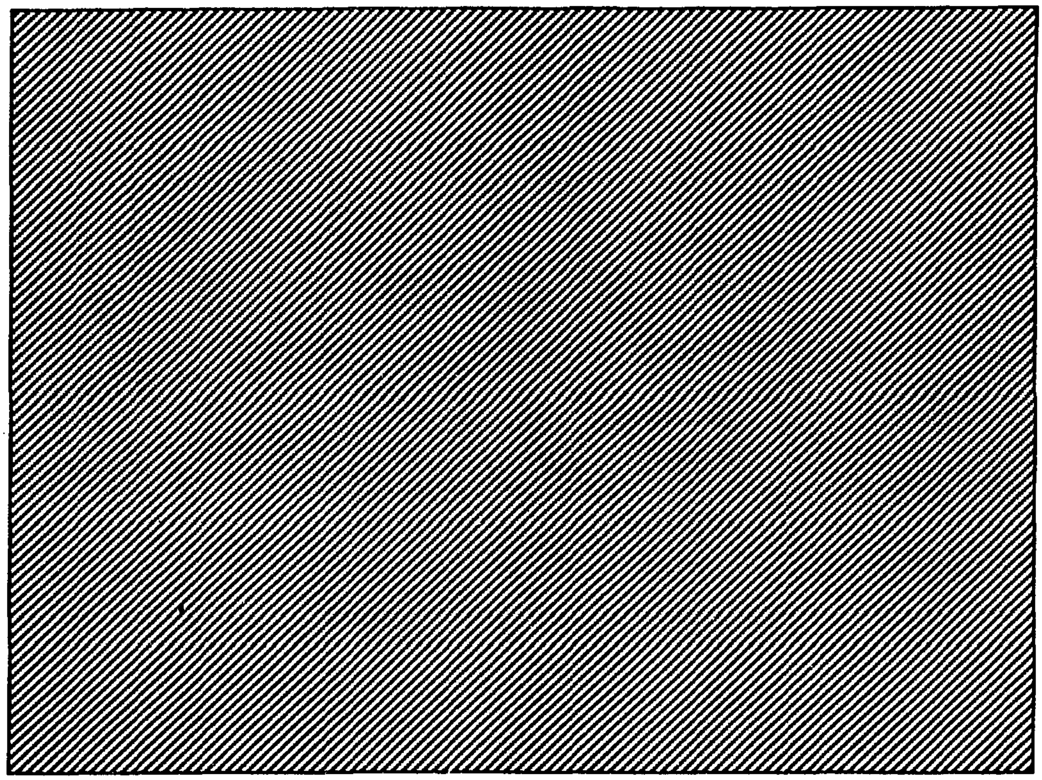


FIGURE 5.27. Moire Vibration

Misra and Ramesh (1969) explain that some of the problems created through the use of texture can be minimized by using textures made up of dot patterns rather than textures made up of line patterns. Raisz (1962) also recommends against textures formed from lines: "Map users prefer fine textures...dot shadings are more pleasing than line shading. Irregular shadings [are] liked the least. One should be particularly cautious about close cross-hatching. In reproduction it easily darkens or clogs, making black patches" (p. 128). Tufte (1983) also points out that commercially produced mechanisms for creating textures, such as computer generated graphics and plastic overlay sheets, can create visually disturbing textures. One flowchart designer interviewed described the difficulties he encountered with the textures imposed on his flowcharts by plastic laminate. The lamination was intended to allow operators to mark on the flowcharts and to erase their marks after use. The texture of the laminate, however, distorted lines and symbols and created disturbing patterns of glare. It was necessary to experiment with several lamination processes to find one with such a shallow and fine grain that it did not impose any texture on the flowchart.

Because of its limitations, then, variations in texture should be avoided in flowcharts. Further, the flowchart designer should ensure that reproduction and lamination of flowchart EOPs do not create unintentional textures that interfere with the legibility of the flowcharts.

5.4 USE OF THE VISUAL VARIABLES IN FLOWCHART EOPs: AN EXAMPLE

The objective of the flowchart designer should be to use the visual variables to convey information graphically. Not only should the correct variable be used to convey a given type of information in a flowchart, but the simplest and clearest means possible of conveying the information should be used. Thus, position and implied movement variation should provide the most important information in flowchart EOPs. Use of these visual variables can then be augmented with careful applications of shape, value, orientation, size, color, and texture variation.

Figures 5.28 and 5.29 demonstrate ineffective and effective use of some of the visual variables discussed in this section. Each figure shows a different flowchart representation of a hypothetical procedure (a structure such as this could appear in either an algorithmic or a big-picture flowchart). A glance at Figure 5.29 reveals a wealth of organizational information that is difficult to see in Figure 5.28, even after studying Figure 5.28 at length. Figure 5.29 provides an example of one possible way to design a flowchart where the relative positions of the flowchart elements, and the lines which connect those elements, provide strong implied movement cues. It has been designed with the prime objective that the graphics of the chart reveal the structure of the procedure by clearly indicating the possible paths of movement through the chart. In contrast, Figure 5.28 has been designed with the prime objective of using space efficiently.

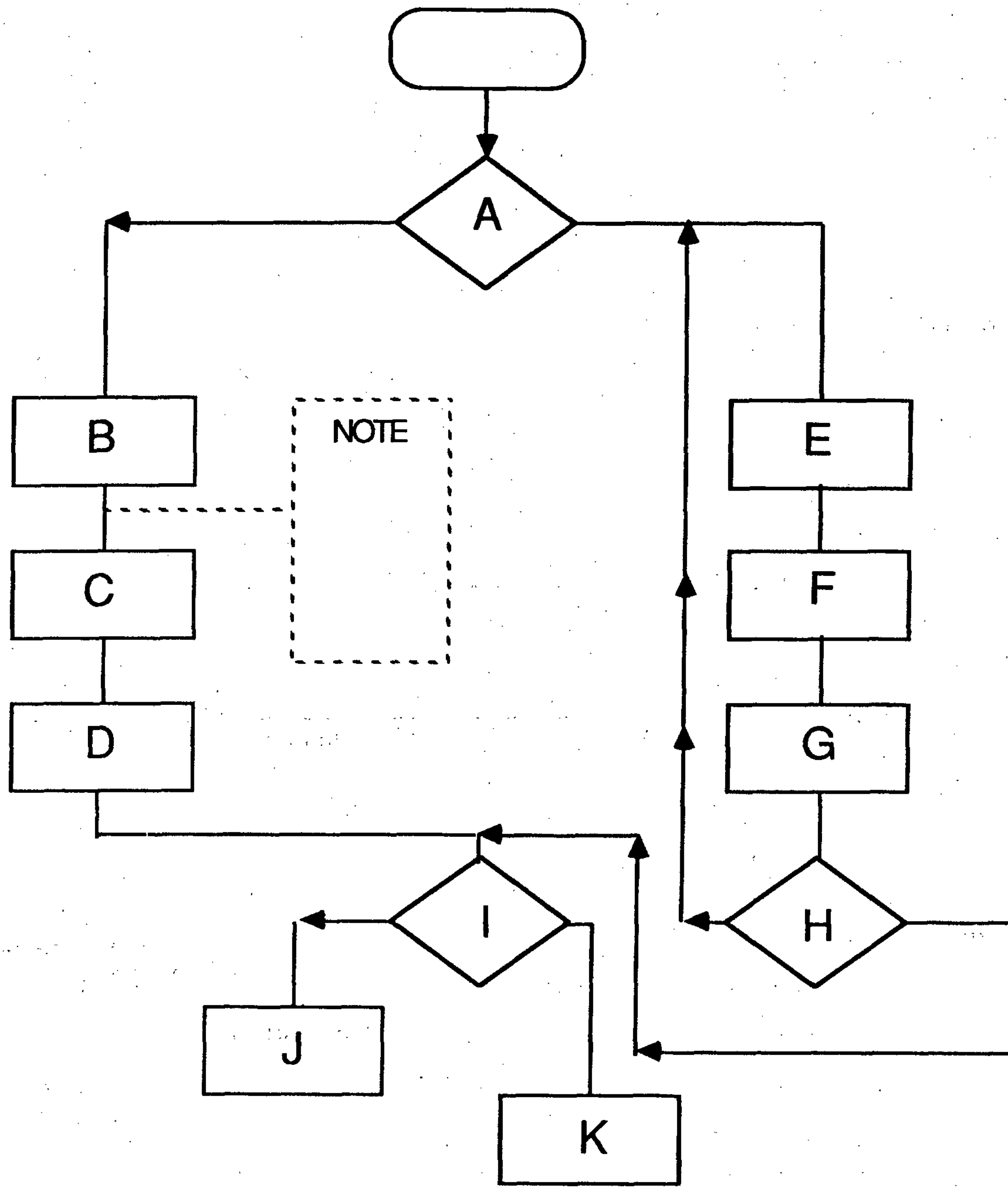


FIGURE 5.28. Flowchart Designed to Save Space (see Table 5-2)

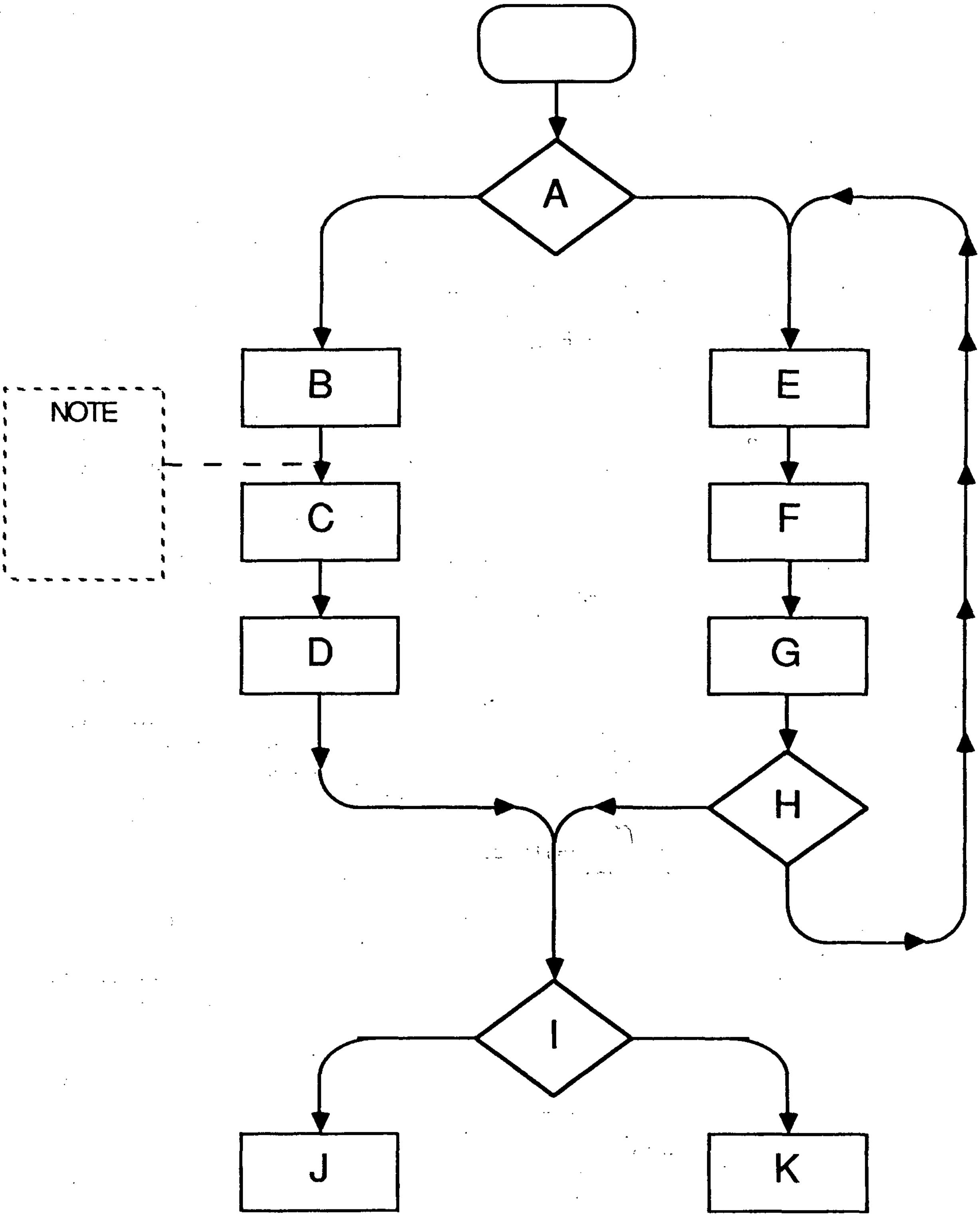


FIGURE 5.29. Flowchart Designed to Convey Information Graphically (see Table 5-2)

Table 5.2 contrasts some of the guiding principles used in the design of each flowchart. Note that these techniques are very brief and general, and are only provided to indicate the types of concerns reflected in each of the flowchart examples. In actual practice, more detailed and specific techniques would be required to assure consistent visual patterns throughout individual flowcharts and sets of flowcharts.

TABLE 5.2. Guidelines Used to Develop Figures 5.28 and 5.29

Figure 5.28	Figure 5.29
All flowchart items will be positioned to provide the most efficient use of the page, i.e., so that the flowchart occupies the smallest amount of space possible. Disadvantage: The poor positioning of steps J and K obscures the fact that the two steps have a parallel relationship.	All flowchart items will be arranged to provide structural cues, even if such an arrangement causes the flowchart to require more space on the page. Advantage: The flowchart forms two logical units: (1) Steps A through H and (2) Steps I through K. The relatively long flowline preceding Step I emphasizes this fact.
The predominate flow of movement through the chart will be from top to bottom. Flowlines will enter all symbols at the tops of the symbols. Supplemental information may be placed to the sides of the main flowpaths. Flowlines may enter supplemental information symbols at either the tops or the sides of the symbols.	The predominate flow movement in the flowchart will be from top to bottom. Flowlines will enter all symbols at the tops of the symbols. Supplemental information may be placed to the sides of the main flowpaths. Flowlines may enter supplemental information symbols at either the tops or the sides of the symbols.
Flowpaths will exit action symbols from the bottom. All flowpaths will exit decision symbols from the sides of the symbols. Disadvantage: The flowpath connecting Steps H and I exits Step H from the worst possible corner of the decision symbol. A shorter, and straighter flowline could have been used if the flowline exited from the bottom of the decision symbol. Such a flowline would be easier to follow.	Flowpaths may exit action symbols from either side or from the bottom of the symbol. All No flowpaths will exit decision symbols from the left (i.e., the movement will be to the right). All Yes flowpaths will exit decision symbols from either the right (i.e., the movement will be to the left) or from the bottom (i.e., the movement will downward). The point of exit of the Yes flow-path from the decision symbol, will be determined by which choice provides the most meaningful graphic cues. Advantage: Steps E through H form a unit of steps that may be repeated, and the looping flowline helps show this by framing the steps. Because the flowline exits from Step H from the bottom of the step, Step H is included in the frame.

TABLE 5.2. (continued)

Figure 5.28	Figure 5.29
Arrows will mark the direction of flowpaths only when the direction of movement is either upwards or to the left. (Top-to-bottom or left-to-right movement is assumed in the absence of arrows).	Arrows will mark the direction of all flowpaths.
Disadvantage: When moving from Step H to Step I, no graphic cues signal that the operator should follow the last turn in the flowline downward to Step I. An operator could easily make the error of following the flowline to Step D.	Advantage: The arrows on the flowline moving down through Steps E, F, and G creates a sense of rhythm that contrasts with the rhythm created by the arrows in the flowline moving up from Step H to Step E. This contrast makes the looping structure more apparent.
Right angles will be used when flowpaths change direction.	Curved lines will be used when flowpaths change direction to lead the eye through the change in direction.
Disadvantage: When moving from Step H to Step I, no graphic cues signal that the operator should follow the last turn in the flowline downward to Step I. An operator could easily make the error of following the flowline to Step D.	Advantage: The curved corners help lead the eye through all turns in flowpath lines. This is most evident in the places where lines merge.
Two types of flowlines will be used: solid and dashed. A solid line is used for the main flowpaths, operators will follow solid lines in the direction indicated by the arrows. Dashed lines lead to supplemental information. Operators will follow a dashed line from a main flowline to a block of supplemental information, read the information, and then follow the dashed line back to the main flowline.	Two types of flowlines will be used: solid and dashed. A solid line is used for the main flowpaths, operators will follow solid lines in the direction indicated by the arrows. Dashed lines lead to supplemental information. Operators will follow a dashed line from a main flowline to a block of supplemental information, read the information, and then follow the dashed line back to the main flowline.

TABLE 5.2. (continued)

Figure 5.28	Figure 5.29
Changes in flowpath direction can be made if those changes save significant space on the page.	No changes in flowpath direction will be made unless those changes provide information. If changes in the direction of flowlines can be made without adding disruptive visual noise, or creating confusing inconsistencies in the flowchart design, and those changes do provide substantial graphic cues, then the lines will be designed to include those changes in direction.
Disadvantage: The abundance of turns in the flowline connecting Step H and Step I makes the flowline difficult to follow and obscures the overall structure of the flowchart.	Advantage: A consistent correlation between movement through the procedure and movement through the chart is readily apparent. Downward movement through the chart correlates with forward movement through the procedure. Upward movement through the chart always correlates with backwards movement in the procedure.
Supplemental information may be placed to the side of a main flowpath. If supplemental information is so placed, it should be placed to the left or to the right of the main flowpath. It should be placed to whichever side provides for the most efficient use of space.	Supplemental information will be positioned near the item or items to which it pertains and away from other flowchart items.
Disadvantage: The note in the flowchart lies between two series of steps that parallel each other (series B-C-D and series E-F-G). This makes the parallel relationship of the two series less readily apparent.	Advantage: The note is clearly associated only with the Steps in column B-C-D, and not with any of the other steps in the procedure.
Aesthetic considerations should be limited to readability concerns.	The flowchart composition should be aesthetically pleasing; that is, the composition should not be overly dense or filled with visual noise. The principle of unity will be followed.

6.0 FLOWCHART LAYOUT

One of the most important tasks facing a flowchart designer is to organize the information contained in an EOP so that it can be presented in the flowchart format. Flowchart layout entails arranging symbols on the flowchart page and using graphic techniques to guide movement through the flowchart so that the image presented is consistent with the technical requirements of the procedure and meets the goals of legibility, meaningfulness, and aesthetics. This section discusses flowchart layout in terms of the sequencing of steps in flowcharts, the value of organizing flowpaths into columns, the ways in which groups of symbols can be structured to show the interrelationships of pieces of information in flowcharts, techniques for presenting supplemental information and the different types of steps used in EOPs, and methods of facilitating placekeeping in flowcharts.

6.1 SEQUENCING STEPS

Care should be taken when determining the sequence of steps in a flowchart to ensure that the sequence is both technically correct and easy to understand. As described in NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982), EOP action steps, both in any flowpath and in any set of concurrently executed flowpaths, should be sequenced (1) to minimize the physical interference of personnel in the control room, (2) to avoid unintentional duplication of tasks, (3) to minimize the movement of personnel in the control room, (4) to be consistent with the roles and responsibilities of operators, (5) to enable the control room supervisor to follow staff actions and monitor plant status, and (6) to be executed by the minimum control room staffing required by the plant's technical specifications.

Most of the sequencing decisions for flowcharts will be dictated by technical necessity. However, when sequencing options do exist, then the decisions of how to sequence steps in the flowchart should be based on a careful evaluation of how the flowchart will be used. As Wright (1982) explains,

> The desire to eliminate redundancy takes a different graphic form in flowcharts. Here the designer's objective may be to have as few choice points as possible. As with tables, the advantage of such a design strategy is that it saves paper. However, from a user-oriented approach, there may be good reasons for structuring the decision sequence in some other way. For example, it can be helpful to have the easy questions early and the harder questions later in the sequence. This will often mean that if readers make a mistake, then a wrong decision made late in the sequence will not take them too far away from the correct goal. Consequently, there is less back-tracking necessary in order to rectify mistakes. (p. 324)

Flowchart designers interviewed for this project agreed that placing difficult decisions later in a flowpath is a nice idea, but pointed out that it is not always possible to adhere to this principle. Sometimes the most difficult decisions that must be made in a flowchart EOP are determining if the entry conditions exist.

Wright (1982) goes on to explain that sometimes it may be advantageous to structure a flowchart in the opposite manner as previously suggested, that is, to arrange the flowchart so that the most difficult steps and unlikely possibilities appear early in the flowchart. She notes, "Sometimes diagnostic trees are designed to exactly the opposite criterion in order to encourage the user to consider the unlikely possibilities" (p. 324).

Although technical necessity will dictate most step sequences in flowchart EOPs, where options do exist, the flowchart designer should consider developing two or more flowcharts that include the various step sequence options. It is likely that some of the options can be ruled out based on a desk-top evaluation of the appearance of the flowchart. To choose among other options, it may be necessary to conduct usability tests with operators in a simulator, if one is available, or during a walk-through of the EOP.

6.2 REFLECTING THE MOVEMENT THROUGH THE FLOWCHART IN THE FLOWCHART'S LAYOUT

Flowcharts should be designed so that the movement through the flowchart is evident from the flowchart's layout. As discussed in Section 5.3.2, either top-to-bottom or left-to-right movement should be used consistently as the primary direction of movement in the flowchart, and the other direction should be used as a secondary direction of movement. Making this distinction between directions of movement will enhance the flowchart in two ways: (1) it will produce a more orderly flowchart where graphic cues are not lost in confusing graphic structures, and (2) additional information about the procedure can be communicated by changing the flow of movement from the primary direction to the secondary direction.

The primary direction of movement in a flowchart should be based upon the actions and decisions operators will need to take to respond to the expected sequence of plant conditions during a transient. In a flowchart EOP with a top-to-bottom primary direction of movement, secondary movement, that is, left-to-right movement, would occur at decision symbols and lead to contingency actions. If the decision steps were written so that the expected response was out of the bottom of the symbol, then a movement out of the side of the symbol would indicate that an expected response had not been obtained. If an expected response was not obtained, the flowpath would either loop upwards or downward, move via a connector symbol or flowline to another part of the flowchart, or enter a parallel flowpath containing a series of contingency steps. The primary direction of movement in this parallel flowpath would again be downward, with unexpected responses sending operators further to the right.

Treating primary and secondary flow directions differently can be used to indicate other types of information as well. Changes in the conventional methods of positioning items in a flowchart will always indicate that some sort of a change in meaning is being cued, whether this is the case or not. For example, Figure 6.1 shows a flowchart that has been arranged vertically.

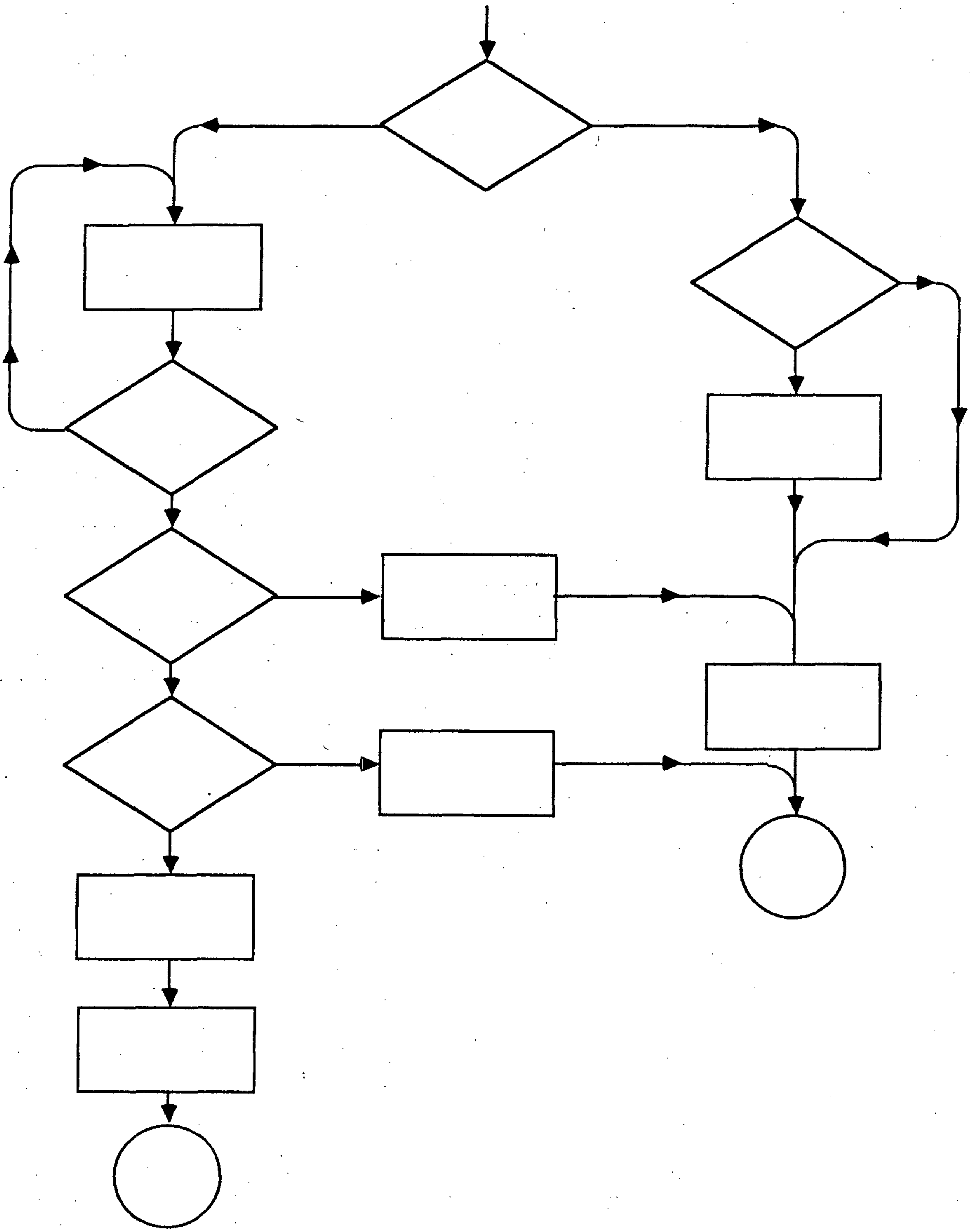


FIGURE 6.1. Looping and Horizontal Flowpaths

In this figure, two horizontal paths have been used to connect two of the main paths. The change of direction in this example is appropriate because it signals a change in meaning; the top-to-bottom paths move the user through one of the main flowpaths and the left-to-right paths move the user from the first main flowpath into the second main flowpath. One piece of information that this flowchart conveys readily is that there are two and only two places where one could move from the first main flowpath into the second main flowpath. In Figure 6.2, a change of direction has been added to the bottom of the first main flowpath. This deviation from the top-to-bottom direction does not convey graphic information, and it obscures the fact that the main flowpaths are only connected in two places. The structure clearly seen in Figure 6.1 can still be found in Figure 6.2, but it is not as readily apparent.

If the top-to-bottom direction of movement is used most of the time, the flowchart will naturally tend to fall into columns. By contrast, if top-to-bottom and left-to-right flows are both used frequently or if both flows are used for complex branching structures, the flowchart will sprawl across the page. Such a sprawling flowchart would be visually confusing, and graphic cues would not be as readily seen as in a more orderly flowchart.

Top-to-bottom primary movement and left-to-right secondary movement in flowchart EOPs is quite similar to the directions of movement required by many two-column text EOPs currently used in nuclear power plants. In these text EOPs, operators perform steps in the left column as long as expected responses are obtained and move to the right column for contingency actions if expected responses are not obtained. Once the contingency actions have been taken, operators return to the left column. Capitalizing upon operators' familiarity with this type of movement through EOPs is likely to make the transition to flowchart EOPs easier for operators.

In all flowchart EOPs examined except CSFSTs, a top-to-bottom flow of movement was used as the primary direction of movement. However, because many of the flowchart EOPs were designed to save space on the flowchart sheet, a secondary direction of movement was not used consistently. In addition to the visual confusion created by this inconsistency, the information that could be provided by maintaining a left-to-right direction of movement for contingency actions was lost in these flowcharts.

6.3 BASIC STRUCTURES

There are eight basic structures that can be used for presenting information in flowcharts. These structures describe the ways in which decision and action symbols can be combined in flowcharts. Merrill (1982) identified six basic structures for computer programming, and we have added two for use in flowchart EOPs.

Merrill's (1980) basic structures are made up of three primitive structures and three variants of those structures. Merrill's primitive structures and their variants are as follows: (1) linear; (2) alternative, which includes one variant, the case structure; and (3) repetitive, which includes two variants, the decision-follows-the-action variant and the abnormal-exit variant. The two structures we have added for flowchart EOPs are another

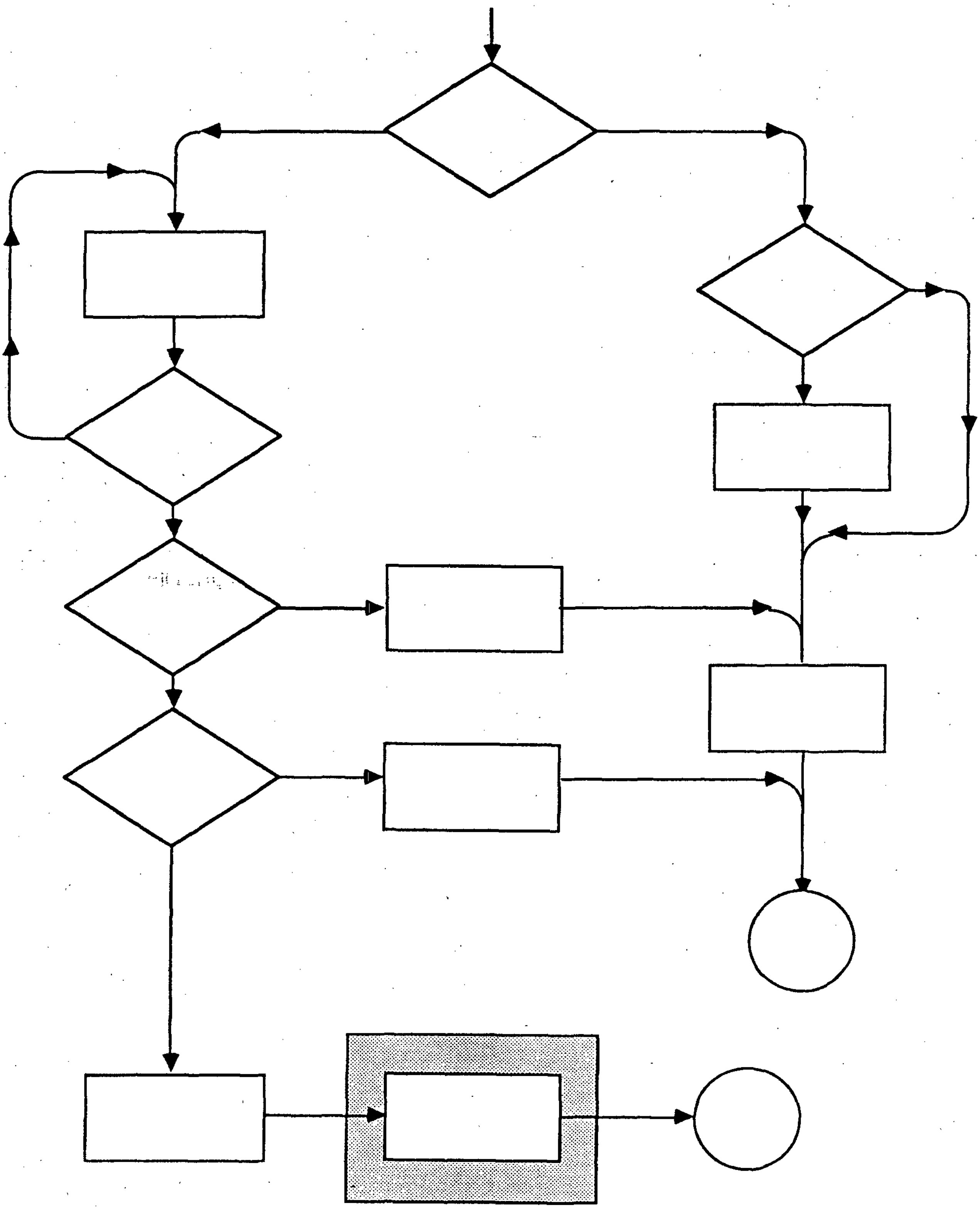


FIGURE 6.2. Horizontal Flowpath That Does Not Add Meaning

primitive structure, the divergent structure, and a variant of the alternative primitive structure, which we have called the bypass alternative. These eight basic structures can be arranged linearly in a flowchart or can be nested within one or more other structures.

6.3.1 The Primitive Structures

Any flowchart EOP can be presented using only the four primitive structures: linear, alternative, repetitive, and divergent. The flowchart representations of these structures are shown in Figure 6.3. The linear structure is simply a series of action steps. The alternative structure consists of a decision step followed by two alternate paths of actions that merge later into a single flowpath. The repetitive structure consists of one or more actions that may be repeated several times. The number of times that the actions are repeated is determined by a decision step. The divergent structure consists of a decision symbol that branches into two or more flowpaths that do not converge. Any flowchart that begins at a single entry point and has more than one exit must contain at least one divergent structure.

6.3.2 Variations of the Primitive Structures

Although any flowchart can be presented using only the four basic structures (linear, alternative, repetitive, and divergent), four additional structures are useful in flowchart EOPs. These additional structures, all of which are variants of the four primary structures, can be used to promote the efficiency of the flowchart. The case structure and the bypass alternative structure are variants of the alternative structure. The decision-follows-the-action and the abnormal-exit structures are variants of the repetitive structure.

6.3.2.1 The Case Structure

The case structure allows for more than two possible flowpaths at a decision step, as shown in Figure 6.4. As is explained below, there are definite advantages and disadvantages to the case structure. A flowchart designer interviewed for this report suggested that flowcharts are more efficient if they do not exclusively use binary decisions.

The relative rarity of case-structured decisions in conventional flowcharts may be a result of the historical development of flowcharts rather than an accurate reflection of the usefulness of the case structure. As Wright (1982) points out, many flowcharting conventions grew out of the use of flowcharts in the computer industry. The binary decision point may reflect the fact that many computer languages are limited to binary decisions.

The case structure is essentially a compromise. By providing more than two options at a decision point, the case structure can simplify a flowchart, but only at the expense of making a given decision more complex.

Regardless of whether a binary or a case structure is used, it is imperative that the flowpaths leaving the decision symbol encompass all possible answers

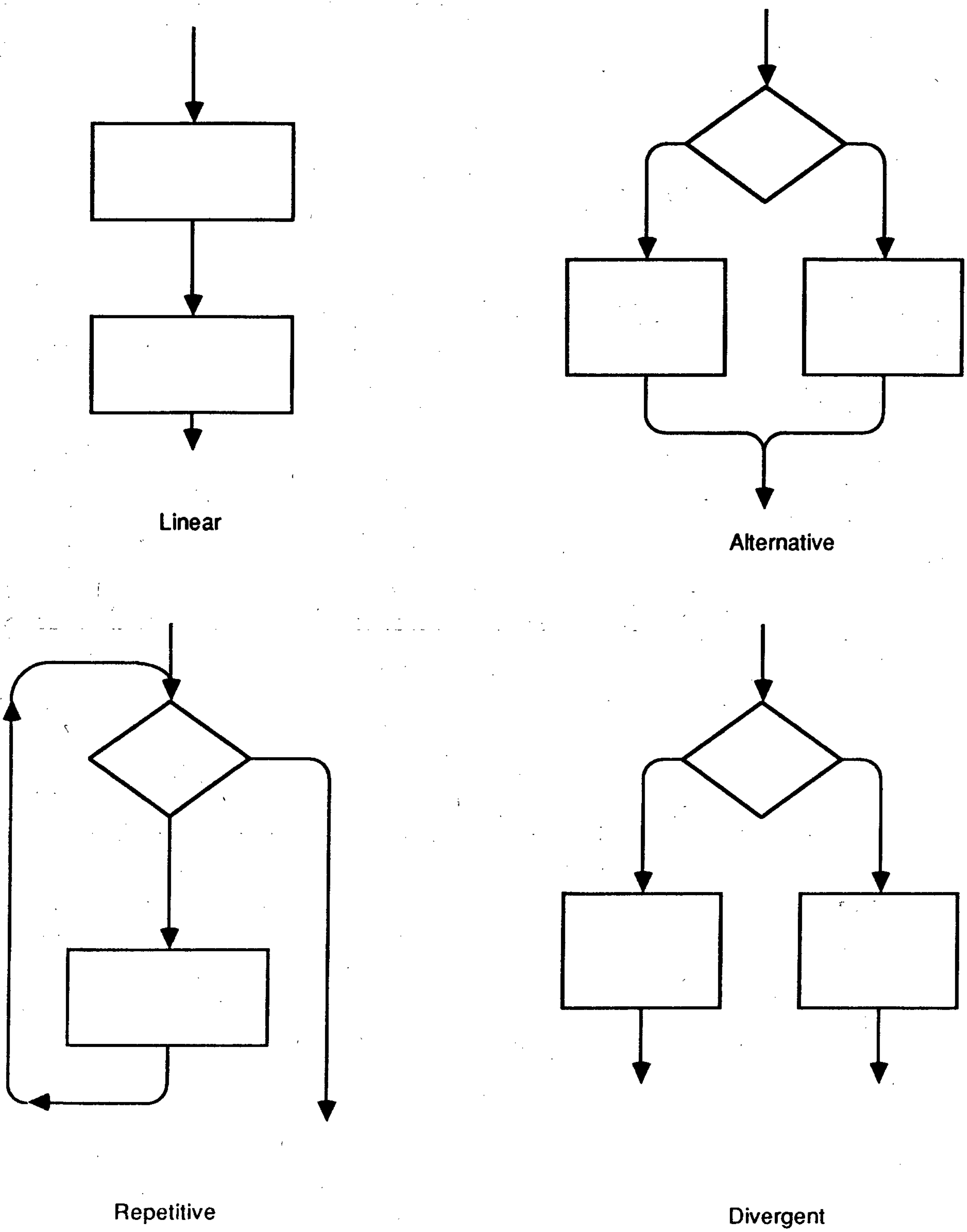


FIGURE 6.3. Primitive Structures

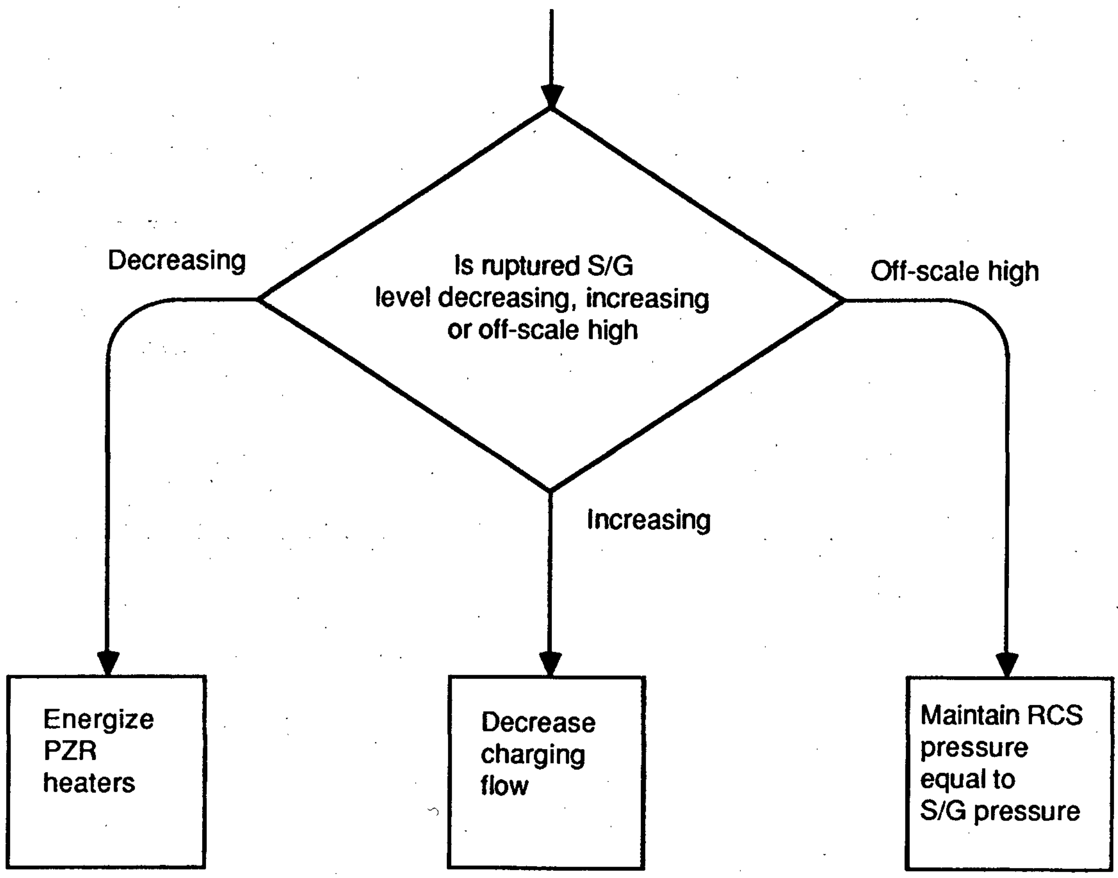


FIGURE 6.4. Case Structure

to the question posed within the decision symbol. Wason (1968) suggests that a binary decision structure be used in the graphic presentation of algorithms to ensure that the flowpath possibilities encompass all possible answers to a question: "these propositions are made exhaustive and exclusive by dividing each into an assertion and its negation. For example, if a clause concerns British citizenship, two propositions are made which exhaust the universe with respect to it: (a) you are a British citizen, and (b) you are not a British citizen" (p. 549). This use of an assertion and its negation provides a built-in test to ensure that flowpaths are provided for each of the possible alternatives at each decision point. If a case structure is used, however, no such built-in test exists. Therefore, special care must be taken to ensure that all possible outcomes are represented in the case structure alternative.

The relative advantages and disadvantages of the case structure in flowcharts have been tested by Kammann (1975) with flowcharts that provided telephone dialing instructions. Kammann conducted experiments comparing the usability of flowcharts with only binary decisions to flowcharts that used the case structure. In the flowchart that used only binary choices, a user could have proceeded through as many as seven decision boxes before reaching an action statement. In the flowchart which used the case structure, the maximum number of decisions that had to be made before reaching an action box was only three. Further, the case-structured flowchart required half as many words as did the binary decision flowchart. Kammann found that the two formats proved equally acceptable in terms of the number of errors made by users of the flowcharts, but users of the case-structured flowchart solved the problems more quickly.

In some applications, the case structure may more accurately represent the decisions that operators must make. That is, it may be advantageous to use the case structure if this structure is a more "natural" presentation of the question. For example, a decision in an EOP may require a gauge reading. The operator would perform one of three different actions depending on whether the reading was normal, above normal, or below normal. The best way for the flowchart to present these alternatives might be by using the case structure with one alternative flowpath for each of these conditions.

6.3.2.2 The Bypass Alternative Structure

There are actually two types of alternatives that flowcharts may need to indicate. These are an alternative with actions, and a bypass alternative. Although Merrill does not draw this distinction, we believe that it raises a formatting concern that should be addressed. In the alternative primitive structure, both flowpaths that are created at a decision point contain actions. In a bypass alternative, one of the flowpaths leaving the decision symbol does not contain actions; it simply directs the operator to bypass the set of actions dictated by the other alternative. A bypass alternative, then, is a forward reference statement.

An examination of these structures shows that the bypass alternative structure appears at first glance to be more similar to a repetitive structure (a backwards reference) than to an alternative structure (see Figure 6.5). In both the bypass alternative structure and the repetitive

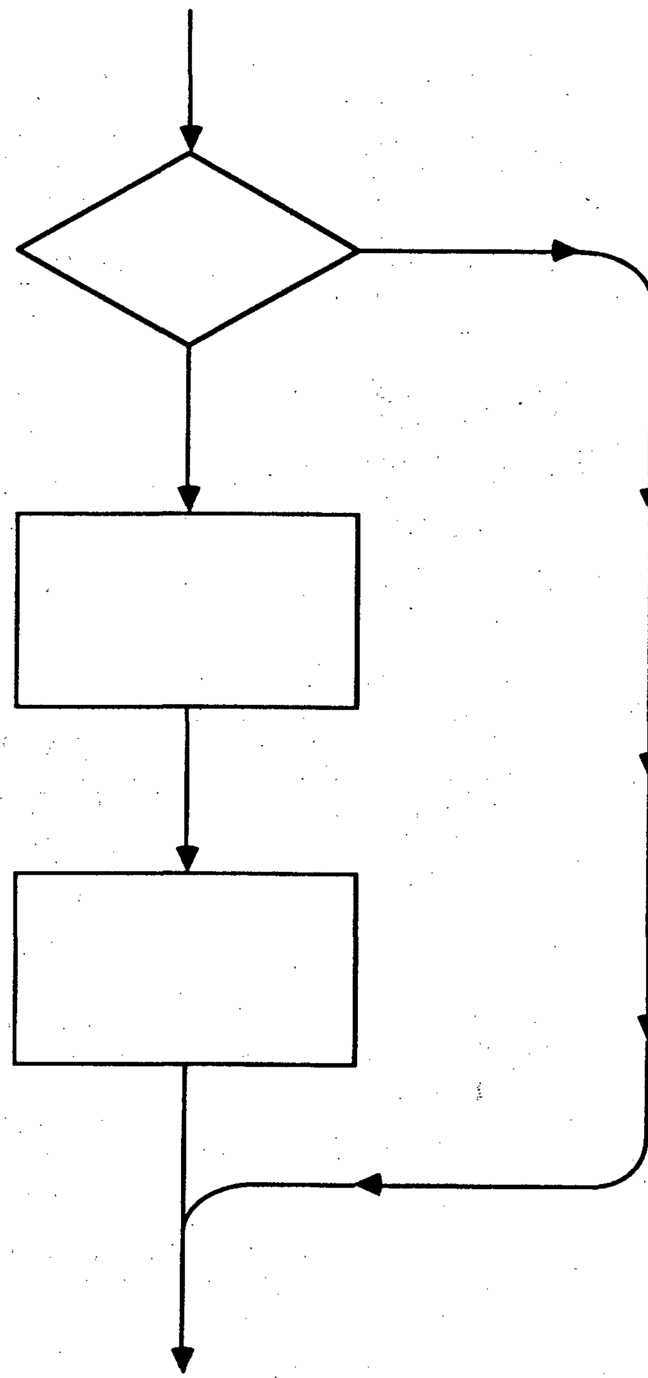


FIGURE 6.5. The Bypass Alternative Structure

structure, a flowline frames a group of steps. In the bypass structure, the steps that are bypassed are framed. In the repetitive structure, the repeated steps are framed. In both structures the frame provides an important graphic cue, but the meaning of the frames is very different. The frames are visually differentiated by the positions of the decision symbols (after the repeated steps and before the bypassed steps) and by the direction of the arrows on the flowlines (in a flowchart with a top-to-bottom movement, the flowline moves down in the bypass frame and up in the repetitive structure frame).

It may be helpful to operators to format these two different structures so that the distinction between them is more obvious. For example, the framing flowline in the repetitive structure could be positioned relatively close to the repeated steps, and the framing flowline in the bypass structure could be positioned relatively farther from the bypassed steps. Alternatively, repetitive loops could always be positioned to one side of the flowpath and bypass flowlines could always be positioned to the other side of the flowpath.

This latter arrangement would allow operators to obtain meaningful information by just glancing through a flowpath. Operators could tell, by which side of the path the loops are on, whether a path contained repetitive structures or bypass alternative structures. A path with repetitive structures may be very time-consuming, because many steps may need to be repeated. A path with bypass alternative structures might be moved through very rapidly, because many steps might be skipped.

6.3.2.3 Variations of the Repetitive Structure

Merrill (1982) recommends two variations of the repetitive structure: the decision-follows-the-action variation and the abnormal-exit variation. The first of these, as shown in Figure 6.6, places one or more actions before the decision step. This structure ensures that the actions which are placed before the decision step are performed at least once, regardless of the decision made. The abnormal-exit variation, shown in Figure 6.7, places a second decision step within the sequence of repeated actions. This variation allows the user to exit the series of repeated steps at a point other than the end of the sequence. This structure can be useful for overcoming the problem of embedded logic steps, which is a frequent problem in text EOPs.

6.3.3 Combining the Basic Structures

The basic structures can be used as tools to help flowchart designers understand the organization of the information contained in a procedure and to determine the best possible flowchart layout that allows the graphics of the flowchart to reflect the procedure's organization. The basic structures provide a method for determining how specific steps should be positioned on the page and may help flowchart designers to place page and column breaks. Limiting flowchart symbol arrangements to the eight basic structures will help ensure that the flowcharts contain consistent visual patterns and it will prevent some especially problematic structures from being included in the flowcharts.

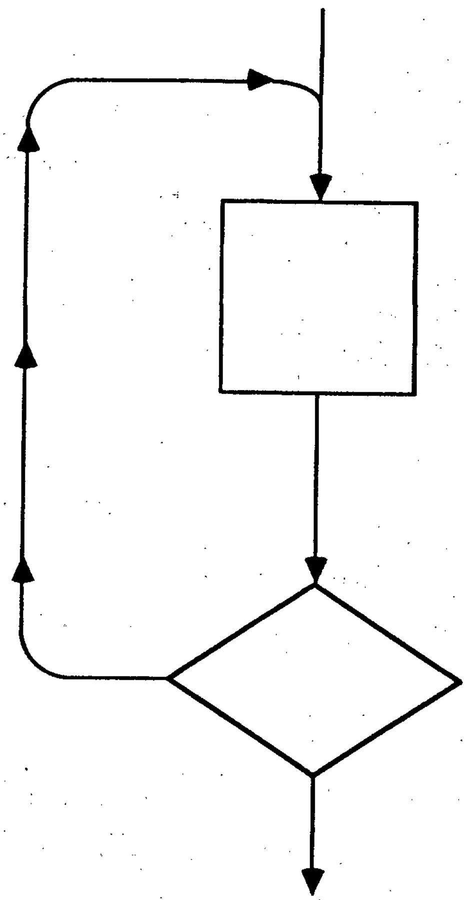


FIGURE 6.6. Decision-Follows-the-Action Structure

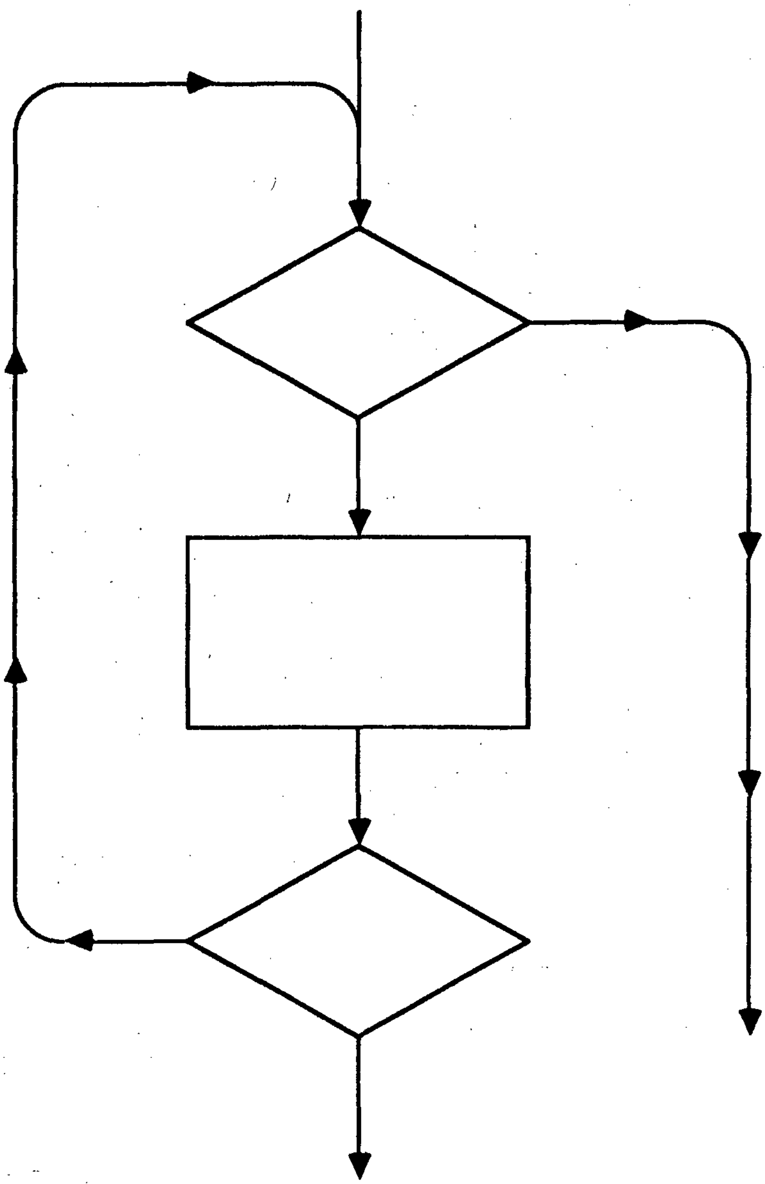


FIGURE 6.7. Abnormal-Exit Structure

6.3.3.1 Nesting the Basic Structures

As noted above, the basic structures can be combined in a simple linear fashion, or they can be nested within one another. Figure 6.8 shows how the primitive structures can be nested in a flowchart. In this example, a linear and a repetitive structure have been nested within an alternative structure. This entire module is followed by a case structure.

Using basic structures to organize the flowchart's layout increases the information provided by the flowchart. Figure 6.9 is an example of a portion of a flowchart drawn without regard to the basic structures. Notice that the logical organization of the flowchart is not evident. Although such a flowchart would probably not increase the possibility of operator error, operators cannot overview this flowchart and quickly understand how the steps are related to each other. A more serious problem is that the flowchart sprawls over the page; a larger flowchart constructed along these lines would be quite chaotic and could be sufficiently confusing that it would lead to operator errors.

These problems are overcome when the basic structures are considered. The flowchart shown in Figure 6.9 in fact consists of a linear structure with an alternative structure nested inside. A second alternative structure is nested inside the first alternative structure. The underlying arrangement of these structures is shown in Figure 6.10, where the shaded boxes are used to represent the two nested alternative structures. In Figure 6.11, this series of steps is drawn according to the basic structures. A comparison of Figures 6.9 and 6.11 reveals the graphic clarity that can be gained in a flowchart by considering the basic structures that these steps create.

The basic structures can be nested at many levels. For example, if a flowchart branches at a decision point at the beginning of the flowchart into two flowpaths, the outermost structure is an alternative structure. The two flowpaths leaving the decision symbol would then be linear structures, with additional structures nested inside.

6.3.3.2 Using the Basic Structures to Place Page and Column Breaks

The basic structures can also be used in a more generalized way early in the flowchart design process. The flowchart designer should consider how series of steps in a flowchart form logical groups, and how these logical groups can be combined through the basic structures. A draft, generalized flowchart can be designed, where single symbols are used to represent groups of actions and decisions. For example, the shaded symbols in Figure 6.10 have been used to represent the nested alternative structures in the path that flows from A to E. This process can help a designer find the least disruptive places for page and column breaks in a flowchart.

Improperly placed page or column breaks can make movement through a flowchart difficult. Such breaks also can destroy graphic cues. It is important, therefore, to choose the points at which a flowchart will be divided into multiple pages or multiple columns carefully. This concern is especially

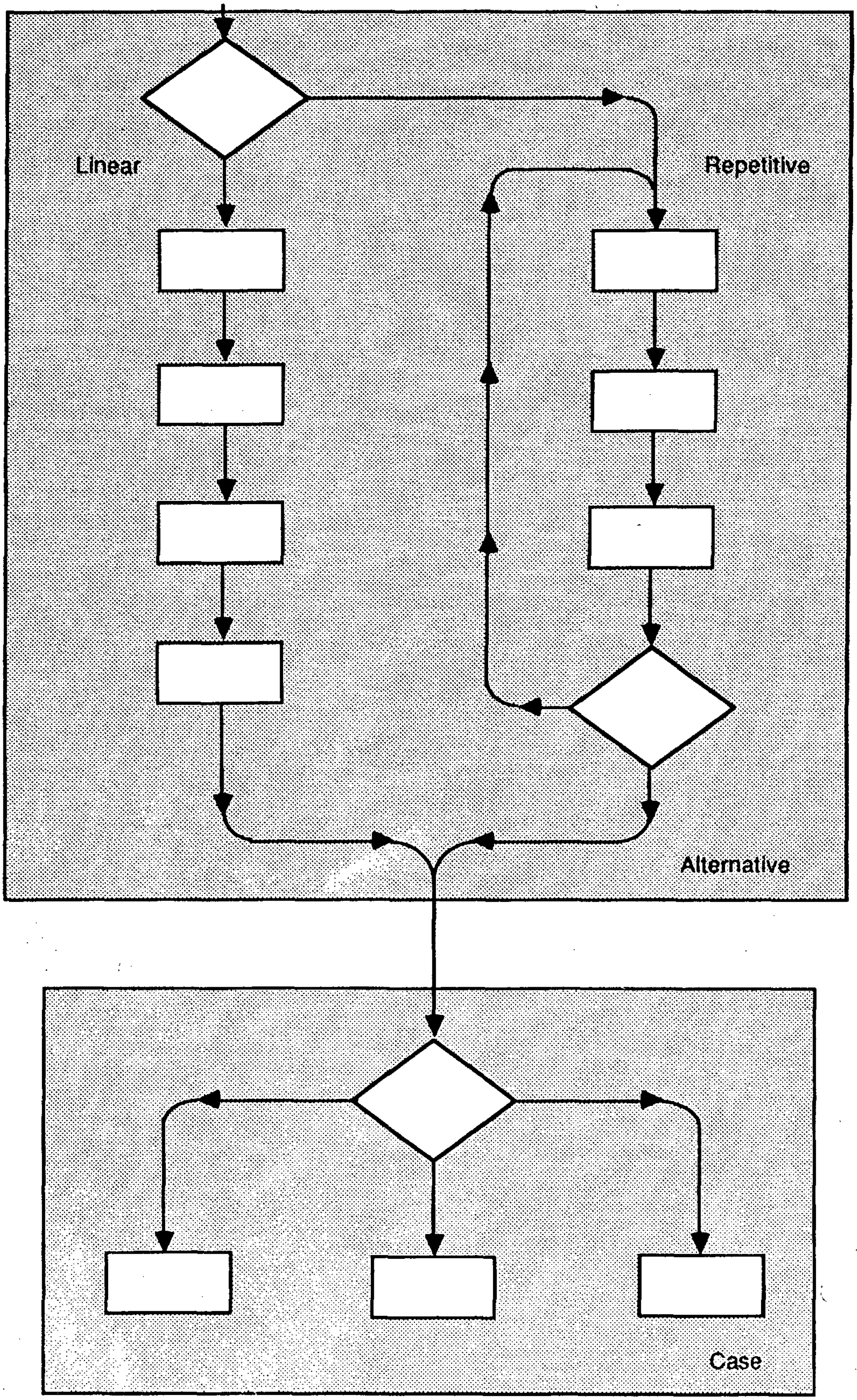


FIGURE 6.8. Nesting of Primitive Structures

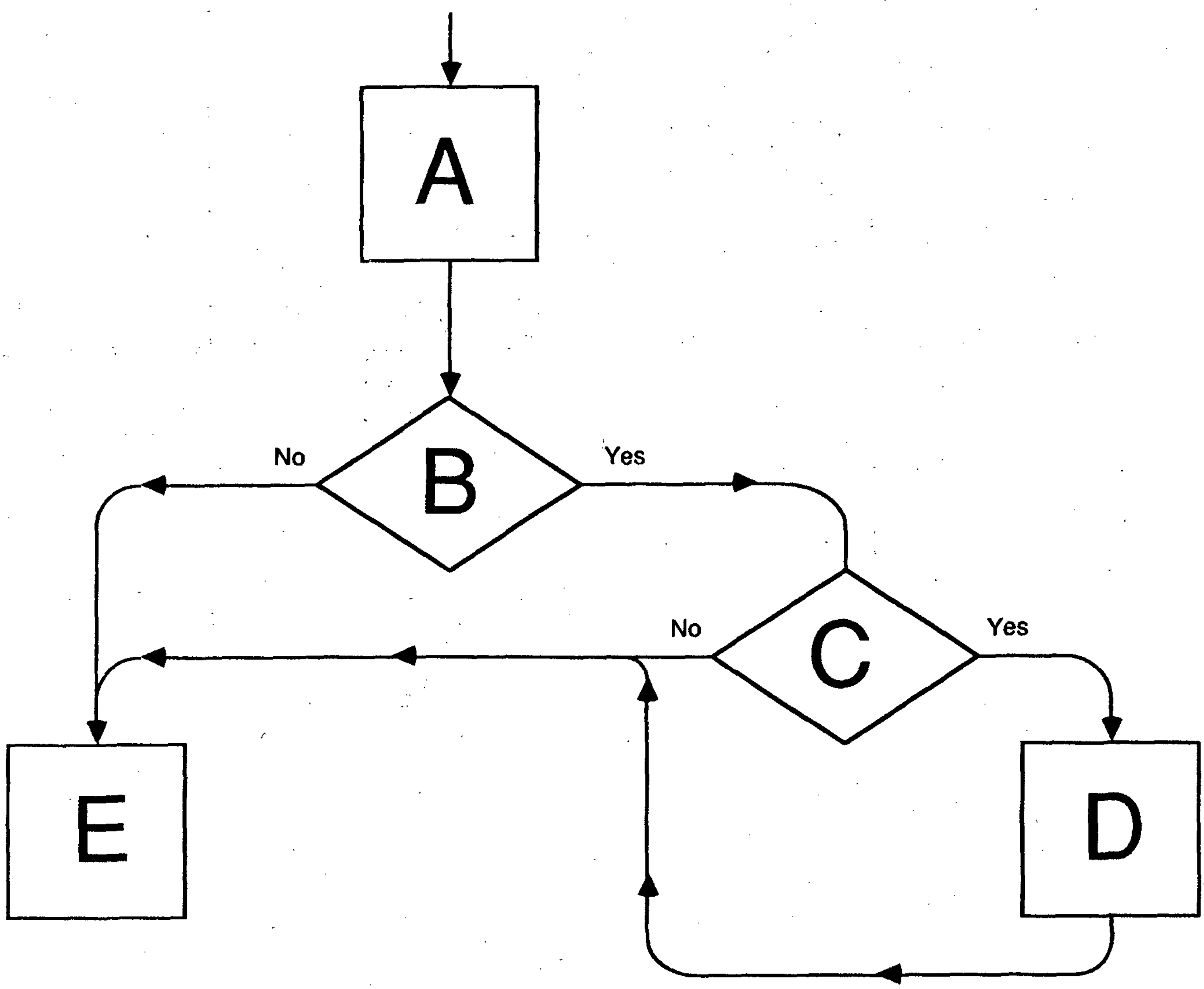


FIGURE 6.9. Representation of a Logic Statement Without Considering the Basic Structures

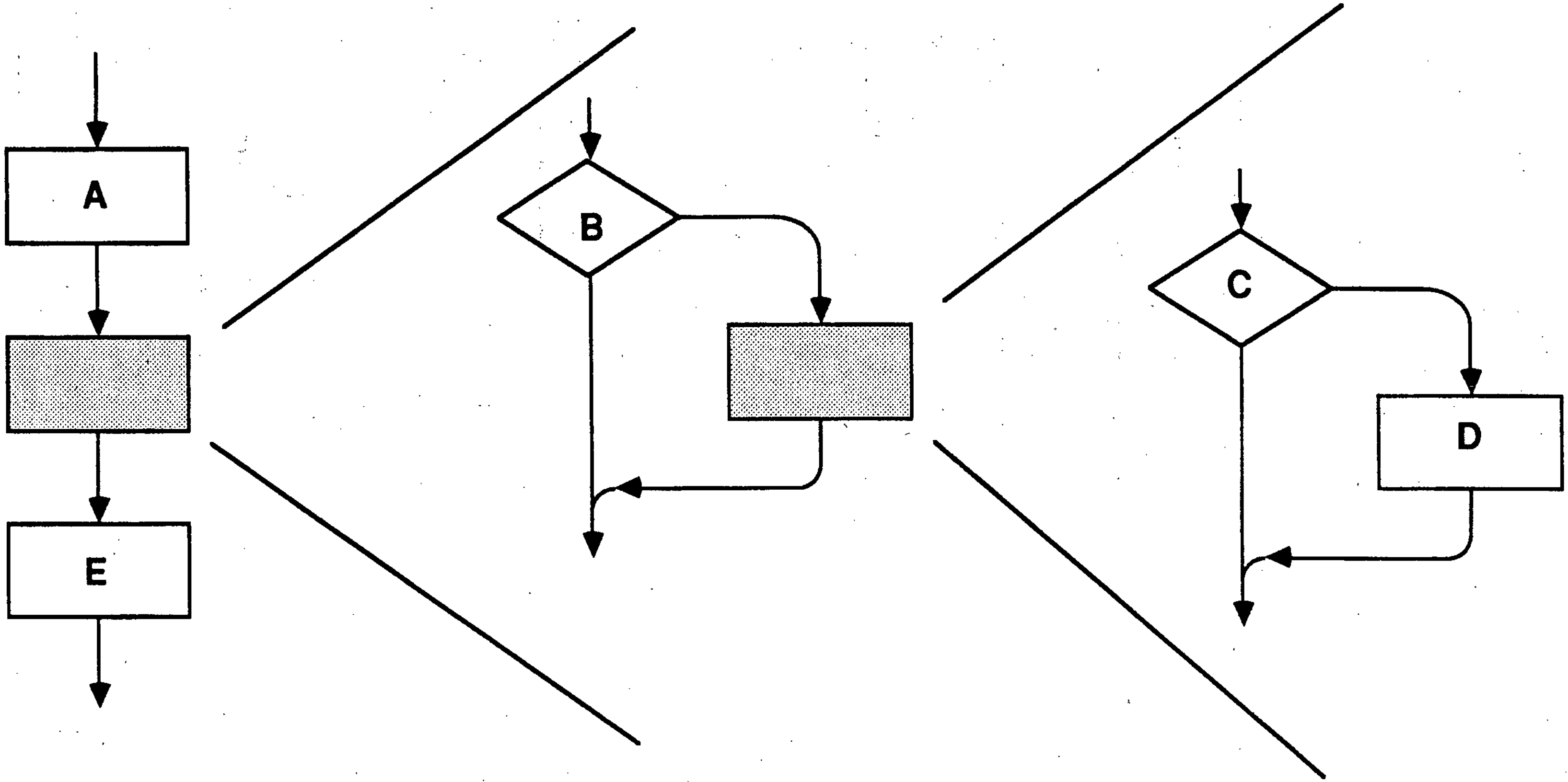


FIGURE 6.10. Nesting of the Basic Structures

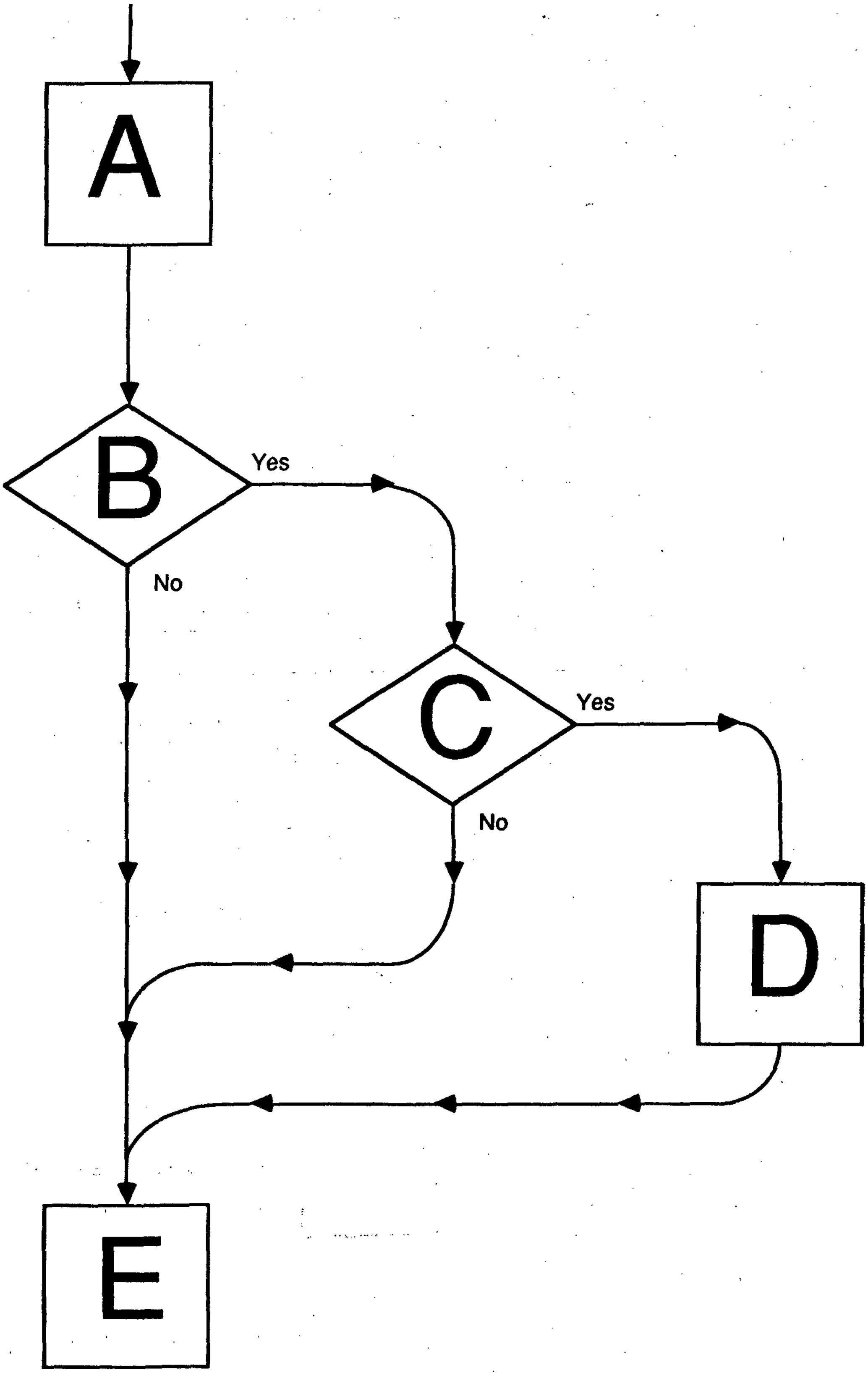


FIGURE 6.11. Representation of a Logic Statement Using the Basic Structures

especially important in algorithmic flowchart EOPs that are typically presented in a multi-column format. Long algorithmic flowcharts frequently require that flowpaths be broken into columns. Several columns that make up the flowpath are then placed side-by-side on a single page. Flowcharts that are especially long must be broken into several pages.

Page and column breaks should occur between the elements within a basic structure at the highest level possible. Preferably, breaks should occur within a linear structure. This rule will minimize the number of flowlines that are broken and will simplify the movement at the break. Consider Figure 6.10 again. A break would preferably occur directly after A or before E in the linear structure. Such a break would only violate one flowline. If a break were placed after B inside the first alternative structure, two flowlines would be violated. In fact, whenever a break occurs within an alternative or a bypass structure, two flowlines must be violated.

In a long procedure that continues through several columns on the page, it may be necessary to use a flowline indicating a movement to another part of the procedure with a left-to-right movement. A bypass alternative (i.e., a structure that directs operators to skip a series of steps) flows in the same direction as the series of steps that are skipped. The flowline moves parallel to the skipped steps, indicating that the operator should go around those steps. However, if the flowpath snakes onto a second column, and the operator is to skip all the steps between a point in the first column and another point in the second column, then a short flowline moving across the page could be used to show the forward reference. This would simplify a complex flowchart by replacing a long vertical flowline with a short horizontal line. However, the flowline indicating a bypass would no longer frame the bypassed steps. To maintain the graphic cue provided by the looping flowline in a bypass alternative structure, the ways in which such forward referencing flowlines will fall on the page should be controlled by carefully selecting the points at which columns will be broken.

6.3.3.3 Structures to Avoid

Combining and nesting the structures in various ways allows for almost limitless possibilities. However, a few awkward sequences of flowchart symbols should be avoided. For example, a repetitive structure that contains only a single question which is continuously repeated until the correct answer advances the operator to the next step should not be used. Such a structure (see Figure 6.12) is graphically strange and should be avoided in flowcharts, although one flowchart EOP examined did include it. When operators encounter such a step they do not do what this graphic representation directs them to do. That is, they do not exit from the step and proceed to where they already are and then do so again. Operators "hold" at that position and wait for a condition to be met before continuing. A more accurate presentation of this step will direct operators to stop and wait rather than to proceed in a small loop. As previously noted, an octagon symbol (as in a stop sign) is one method of conveying this idea graphically (see Figure 6.13).

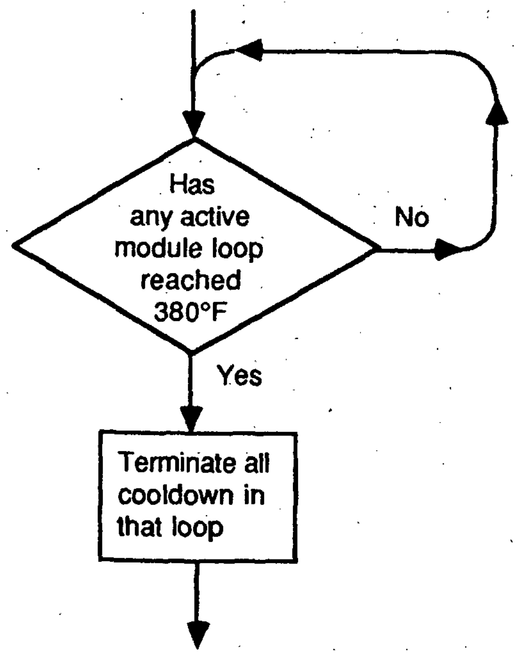


FIGURE 6.12. Repetitive Structure That Contains Only One Decision and No Actions

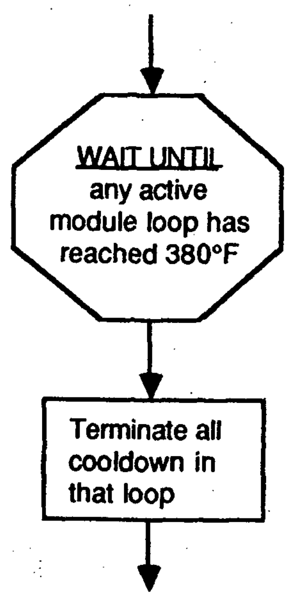


FIGURE 6.13. Use of a Hold Symbol to Present the Steps in Figure 6.12

Use of the basic structures also prevents the inclusion of decision steps in an EOP where operators select more than one alternative at the same time, although concurrent actions can be presented. However, operators will only be able to follow concurrent paths if the graphics of the flowchart readily and accurately show all of the paths separately on the page rather than embedded in a single flowpath. Unless it is drawn to be graphically distinct, a concurrent path structure for actions within a flowpath could be easily confused with a typical alternative structure for decisions.

6.3.3.4 Parallel Flowlines in Nested Structures

Nesting structures can lead to constructions containing closely spaced parallel flowlines. Such arrangements of flowlines can be visually confusing and can lead to operator error. Generally, parallel flowlines should be spaced relatively far apart on the page, so that they are clearly separated with white space. However, excessive white space within a unit of nested structures will obscure the relationships graphically shown in the layout of the structures.

If the parallel flowlines lie in nested structures in the same flowpath, then there is a logical reason for them to remain close to each other. Figure 6.14 shows flowlines spaced in this manner. As previously discussed, the flowlines of repetitive structures and bypass alternative structures should frame the repeated or bypassed steps. However, if such structures are nested within each other, and the resulting parallel flowlines are widely separated, then the frames of the outermost structures in the nest will be moved farther away from the framed steps. As the nest becomes larger, it will be more difficult for an operator to see which steps are included within each frame, and the graphic cues provided by the frames will become less meaningful. Consequently, creating more space between the parallel flowlines will make some graphic cues less apparent. A point is reached where moving the lines farther apart can diminish the effectiveness of the graphics. Further, there is generally little space available in a flowchart for the luxury of presenting flowlines in this manner.

It may be advantageous to enhance the visual separation of the parallel flowlines through another type of visual variation. Because the variation is being applied to a flowline, and because the purpose of the variation is to clarify the different flows of movement, an obvious tool for creating this variation is the planar variable of implied movement. The sense of implied movement in each of the lines can be varied by changing the proportion of each line that is occupied by arrows, as shown in Figure 6.15. Because the arrows along the flowlines create a sense of rhythm, and rhythm affects the perception of implied movement, changing the relative distribution of the arrows will create a different sense of implied movement along the different lines. Varying the arrow distributions will also change the perceived value of the lines; because the arrows are dark, those lines with more arrows will be darker.

Implied movement variation and value variation are both dissociative, therefore the perception of this variation will be immediate and obvious.

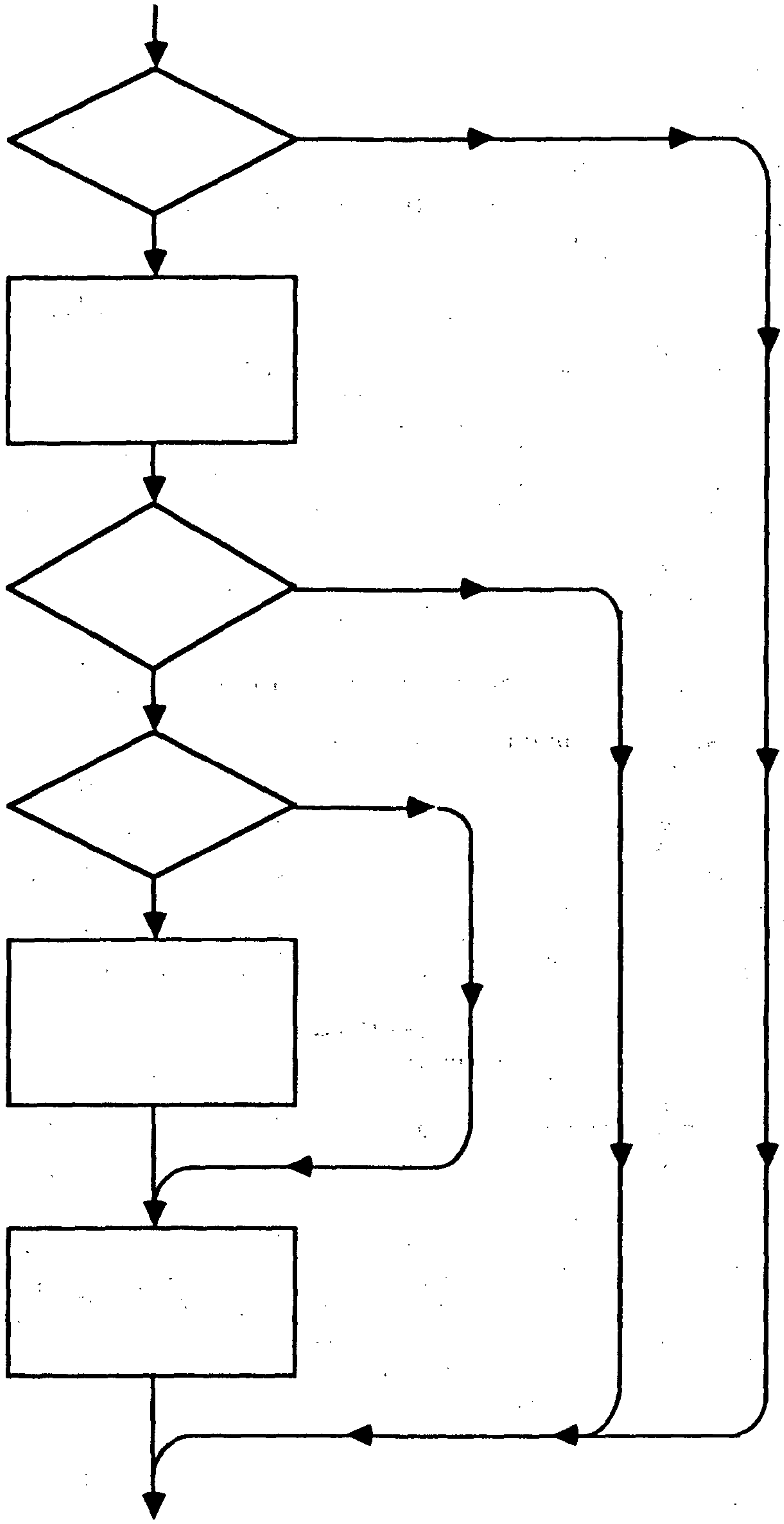


FIGURE 6.14. White Space Used Alone to Differentiate Flowlines

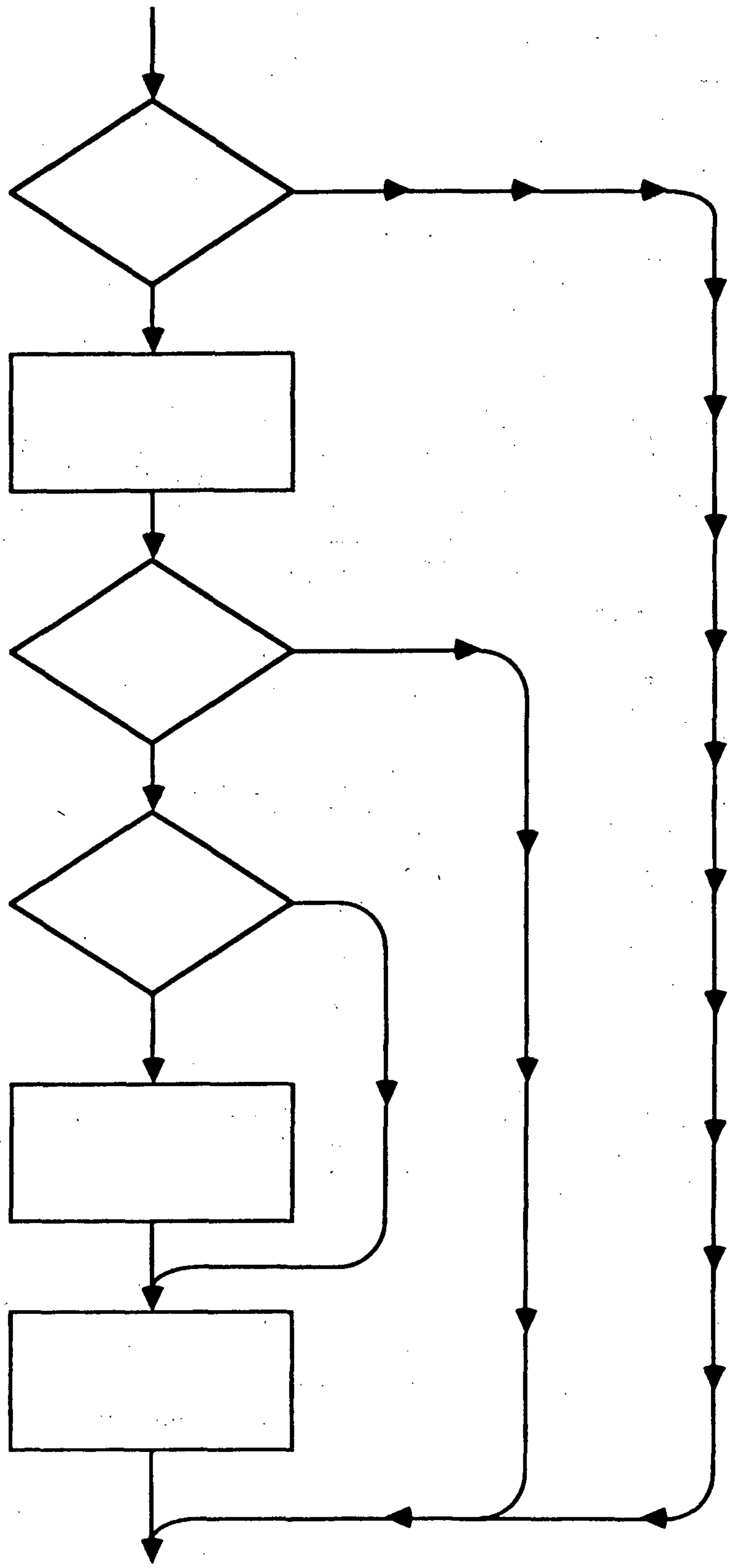


FIGURE 6.15. Spacing of Arrows Used to Differentiate Flowlines

Value variation is selective, so it will be easy for operators to correctly select a chosen line. However, value variation is also ordered. Therefore, the progression from the line with the lowest density of arrows to the line with the highest density of arrows should mirror the hierarchical order of the structures. If the distribution is arranged so that the outermost lines have the highest density of arrows, then the more global structures will have the darkest values. This convention will also place arrows most frequently on the longest lines, where they are most needed.

6.4 PRESENTING THE TYPES OF STEPS NECESSARY IN EOPs

As discussed in NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982), EOPs typically require the presentation of several different types of action and decision steps. These include simple action steps, verification steps, nonsequential steps, equally acceptable steps, recurrent steps, time-dependent steps, and concurrent steps. In this section, the suitability of these different step types for use in flowcharts and methods of presenting them with the basic structures are discussed.

6.4.1 Action Steps

As has been previously discussed, the traditional rectangle is an appropriate symbol for action steps in flowcharts. This shape can be easily recognized, operators are likely to be familiar with its meaning, and the symbol uses space efficiently. Keeping the width of the rectangles constant makes the flowpath fall into neat columns. However, rectangles can be lengthened to accommodate long blocks of text.

In the big-picture flowcharts examined, a rectangle is often subdivided with horizontal lines and separate actions are placed within each section of the box. This technique provides a means of grouping related steps. If higher-level steps and substeps are placed in the same symbol in big-picture flowcharts, the format of the text within the symbol should make this relationship obvious to ensure that the steps are not performed twice (once when the higher-level action is encountered and again as the substeps are performed). The clearest presentation of this hierarchy is the structure operators are familiar with from text procedures, that is, numbering or bulleting the steps and substeps to indicate the relationship and indenting the substeps.

The syntax of actions steps should conform to the guidelines in NUREG-0899 (USNRC, 1982). For instance, only action verbs from an approved list should be used and symbols that are not divided should not contain more than one action, unless those actions are closely related.

6.4.2 Decision Steps

There are three ways of formatting decision steps in flowcharts: (1) as structures based upon flowchart decision symbols, (2) as logic statements, or (3) as decision tables. Different methods work best in different types of flowcharts and for different types of decisions. Flowchart designers should attempt to use one method as consistently as possible throughout their flowcharts, however.

6.4.2.1 Decision Symbols

Algorithmic flowcharts are beneficial decision aids because the decision points lead the operator through the appropriate actions and subsequent decisions. Therefore, alternative structures should be the predominant means of presenting decisions in algorithmic flowcharts. As described in Section 6.3, decisions can best be presented in algorithmic flowcharts by using the alternative, repetitive, and divergent basic structures and their variants.

If the exits from decision symbols are fixed (e.g., "yes" is always out the bottom), it will occasionally be necessary to change the wording of decision steps; for example, it may be necessary to ask "Is the valve open?" rather than "Is the valve closed?" Or it may be necessary to ask if more than three pumps are operating, as opposed to less that four.[1] Resulting questions may be phrased in a manner that is not intuitive to operators. Flowchart designers interviewed for this report acknowledged that phrasing questions is especially problematic in algorithmic flowcharts, where the primary reason for using the chart is to simplify the decision process.

Questions should be phrased so that they are easily understood by operators, and some question constructions may be preferred simply because they are more natural for operators. This advantage is clearly lost if awkward double negatives must be used in order to establish consistent exits from decision symbols. Consequently, if the flowchart designer is faced with using many awkward questions in a flowchart, it may be better to mix the directions of exit from decision symbols, rather than to attempt to exit consistently in one direction.

6.4.2.2 Logic Statements

Because big-picture flowcharts are not intended to support decision-making with graphics, they may include decision steps presented as logic statements in rectangular action symbols. A number of the big-picture flowcharts examined followed this convention.

This combination of logic statements with action symbols, however, is potentially subject to the problems of confusion inherent in the use of logic statements in text procedures, and may in fact be even more confusing, since action symbols are being used inconsistently to present both action instructions and decisions. Therefore, it is particularly important that the guidance provided in Appendix B of NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures, be followed when constructing logic statements for big-picture flowcharts. It may also be useful to develop a different symbol from the rectangular action symbol to indicate that a decision is required. The decision diamond can be used in big-picture

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[1]Sentences that use the word "more" are easier to understand than questions that use the word "less" (Wright, 1982).

flowcharts, or one of the two other decision symbols shown in Figures 5.19 and 5.20 in Section 5.0, page 5-31.

Logic statements should be avoided in algorithmic flowcharts. The only instance in which logic statements are useful in algorithmic flowcharts is for presenting hold points written as WHEN...THEN logic statements in octagonal symbols.

6.4.2.3 Decision Tables

Another technique for presenting decision steps that can be used in both algorithmic and big-picture flowcharts is the decision table. Decision tables are a format for presenting many decision points in the form of a table (Schmidt and Kavanagh, 1964a, 1964b; Merrill, 1980). A decision table consists of two regions, one that specifies the conditions, a set of which must be satisfied simultaneously; and one that specifies actions, which are taken when the corresponding conditions are satisfied (Metzner and Barnes, 1977). Figure 6.16 shows an example of a one-dimensional decision table and Figure 6.17 shows an example of a two-dimensional decision table.

There are cases when a decision table within a flowchart may be preferable to a series of flowchart steps. For simple problems, Wright and Reid (1973) found that decision tables could be used more quickly than flowcharts. However, Wright (1968) found that tables presented in a two-dimensional matrix were difficult to understand and that their use could lead to errors. These errors may result from the nature of the matrix table, where users find the correct piece of information at the intersection of a row and column. Users are required to remember two pieces of information (that is, the correct row and the correct column) which may be difficult (Wright and Fox, 1972; Wright, 1982). Therefore, two-dimensional decision tables may be too complex for use in flowchart EOPs.

A crucial difference between the ways in which a basic structure of flowchart symbols and a decision table are used is that decision tables cannot be used in situations where actions taken affect subsequent decisions. When using a decision table, an operator must make all the decisions at once, before any actions are taken. By contrast, in a basic structure of flowchart symbols, decisions can be made after actions are taken that may influence those decisions (Maes, 1978; Fitter and Green, 1979).

Fitter and Green (1979) present an example that illustrates this limitation. In their example a man goes into a restaurant to order a meal. He must make three decisions before deciding what to order: is he hungry, is he thirsty, and is he rich? If he is hungry he will order soup before the meal; if he is thirsty he will order coffee after the meal; and if he is rich he will order steak instead of fish. In this decision table, all of these decisions must be made at once (see Figure 6.18). The man must decide before the meal whether or not he will be thirsty after the meal. If the food is salty, the meal will make him thirsty; yet he cannot take into account the unknown consequences of ordering the food when deciding whether or not to order coffee, which would quench his thirst.

Adequate Subcooling Margin

RCS PRESS	MARGIN
> 1500 psig	Maintain ≥ 20 °F
≤ 1500 psig	Maintain ≥ 50 °F

FIGURE 6.16. One-Dimensional Decision Table

RCS Temp Indication

	RCP ON	RCP OFF	
		Natural Circulation	No Natural Circulation
HPI ON	Tc	Incore T/C	Incore T/C
HPI OFF	Tc	Tc	N/A

Incore T/C is the average of the 5 highest incores.

FIGURE 6.17. Two-Dimensional Decision Table

hungry?	Y	Y	Y	Y	N	N	N	N
rich?	Y	Y	N	N	Y	Y	N	N
thirsty?	Y	N	Y	N	Y	N	Y	N
soup	x	x	x	x	-	-	-	-
steak	x	x	-	-	x	x	-	-
fish	-	-	x	x	-	-	x	x
coffee	x	-	x	-	x	-	x	-
pay bill	x	x	x	x	x	x	x	x

FIGURE 6.18. Decision Table in Which All Decisions Are Made Before Any Actions Are Taken

Source: Adapted from When do diagrams make good computer languages? by M. Fitter and T. R. G. Green, International Journal of Man-Machine Studies (p. 245), vol. 11, 1975.

A series of decision tables can be constructed to allow the hungry man to postpone his decisions to the appropriate parts of the meal, as shown in Figure 6.19. However, the tables in Figure 6.19 are very difficult to follow and require more space to present than the decision table in Figure 6.18.

By contrast, a flowchart consisting of basic structures to present these decisions (see Figure 6.20) is much simpler to follow than either the single decision table shown in Figure 6.18 or the series of decision tables shown in Figure 6.19. Further, the flowchart version does not require that all decisions be made simultaneously, although it does use more space on the page than the decision tables. Two conclusions can be drawn here: (1) decision tables cannot be used when actions taken can affect decisions and (2) if the decisions in an EOP can all be made at the same time and are not affected by the actions that will be taken, a decision table can present the information more concisely that can a basic structure of flowchart symbols.

There is a further limitation to the use of decision tables in flowchart EOPs. Although decision tables can present decision criteria and allow operators to choose from several actions, they would not allow operators to choose from several flowpaths without using branching statements and connector symbols within the table. Requiring the operator to branch to another part of the flowchart or to another flowchart from the table may introduce placekeeping difficulties and make the graphics of the tables more complex. When decision tables are placed in flowcharts, there should be only a single exit point from the table to avoid graphic clutter and potential confusion. If properly constructed, the operator will enter the table, perform the action(s) indicated in the table, and move on to the next symbol along the flowpath. Decision tables should not be used when the alternative actions contained in the tables include long or complex courses of action.

To illustrate this point, consider the earlier example of a decision based on a gauge reading that might be below normal, normal, or above normal. If, based on the reading, the operator should perform a single action and then continue, the decision criteria and actions could be placed in a decision table. However, if each of the three readings indicated a long set of specific actions, then a decision table would have to present three branching statements to three flowpaths, which would be difficult to connect to the table in a graphically unambiguous manner. A case structure made up of flowchart symbols would be a much simpler means of presenting the information. A question would be placed within a symbol, and three courses of action would be indicated by three separate flowpaths, each of which could contain series of actions or additional decision steps.

Many of the advantages of using basic flowchart structures, as described in Section 6.3, are lost when decision tables are used. A decision table cannot convey the organization of the procedure graphically as well as flowchart symbols. More important, even the simple decision table in Figure 6.18 could be difficult to use, because a user might lose his place among the Ys and Ns along the top and wind up in the wrong column. This table, difficult to use now, would become unmanageable if a fourth decision criterion were added. (Such an addition would double the number of columns in the table.) A

Meal

hungry?	Y	N	
soup	x	-	
CALL (rest of meal)	x	x	(Main table)
pay	x	x	

Rest of meal

rich?	Y	N	
steak	x	-	
fish	-	x	(Subtable)
CALL(coffee)	x	x	
RETURN	x	x	

Coffee

thirsty?	Y	N	
drink coffee	x	-	
REPEAT	x	-	(Subtable)
RETURN	-	x	

FIGURE 6.19. Decision Table in Which Actions Are Taken Before All Decisions Are Made

Source: Adapted from When do diagrams make good computer languages? by M. Fitter and T. R. G. Green, International Journal of Man-Machine Studies (p. 243), vol. 11, 1975.

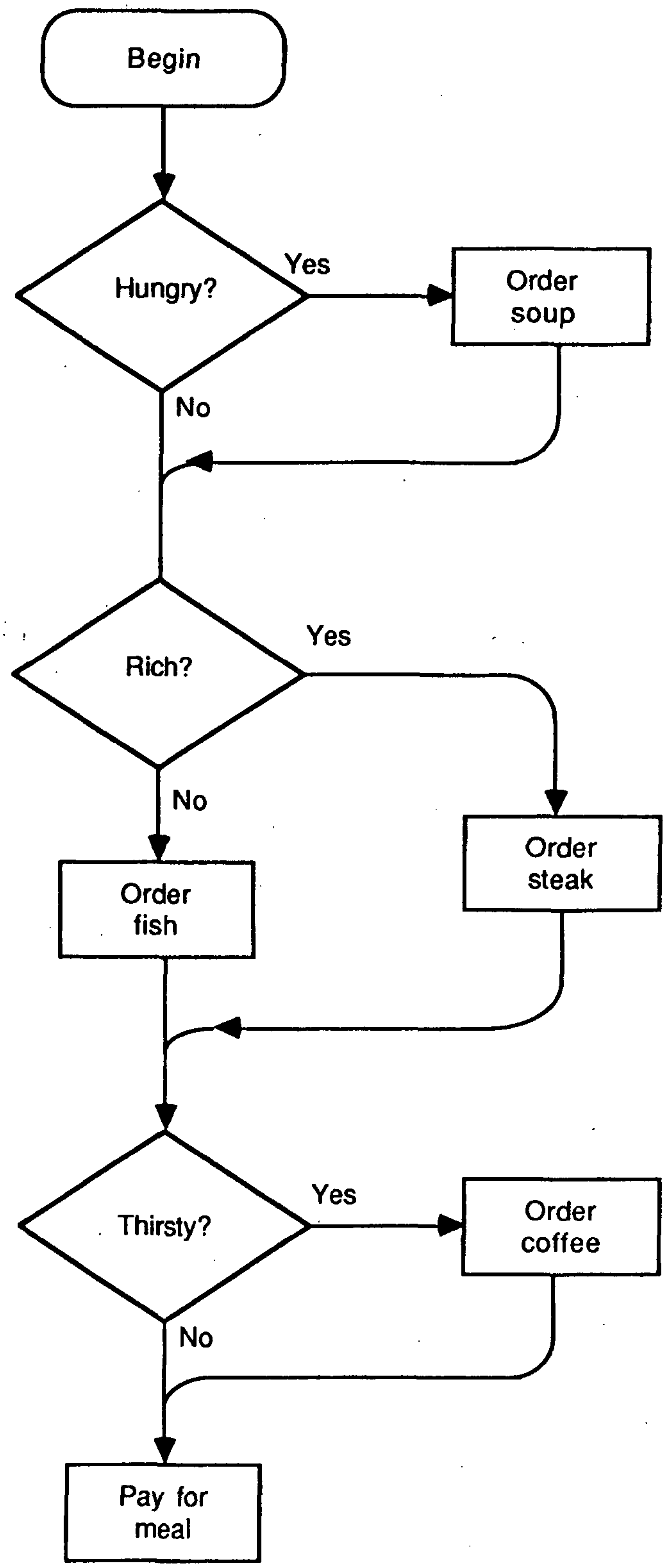

FIGURE 6.20. Flowchart in Which Actions Are Taken Before All Decisions Are Made

Source: Adapted from When do diagrams make good computer languages? by M. Fitter and T. R. G. Green, International Journal of Man-Machine Studies (p. 243), vol. 11, 1975.

similarly constructed table in an EOP could easily lead to operator error when used in a stressful situation or under time constraints.

The greatest advantage of a decision table in flowcharts is that it can be used instead of a logic statement that would otherwise require a combination of AND and OR, as shown in Figure 6.21. Combinations of AND and OR in logic statements can be difficult to understand (NUREG-0899; USNRC, 1982). In other situations, flowchart symbols appear to be a superior method of presenting decision criteria.

6.4.3 Verification Steps

EOPs frequently contain steps that direct operators to ensure that something has happened. These steps are made up of a decision and a closely related action. In these verification steps, operators are directed to check to see if something has happened, and, if it has not, the operator typically is required to initiate the action manually.

Such steps could be structured as a bypass alternative. In such a structure, operators would be presented with a decision step that called on them to check the plant parameter. If the parameter met the necessary conditions, the operator would bypass the next step. If the parameter did not meet the necessary conditions, the operator would proceed to an action step that directed him to initiate the appropriate actions.

There is a more space-efficient structure that could be used to format verification steps. This structure would reduce the graphic detail of the step by combining both the decision and action into a single step. The simplification would be made by structuring the step as an action step using the action verb "verify." Provided that operators are trained that "verify" means to check something and, if necessary, to initiate it manually, this structure would provide the same information as the bypass alternative structure and it would use less space. If operators need detailed instructions on how to initiate the action, however, a bypass alternative structure should be used, with detailed instructions provided as a sequence of action steps within this structure.

6.4.4 Nonsequential Steps

Some steps in EOPs cannot be executed at a predictable place within the flow of actions. There are three types of nonsequential steps in EOPs: (1) steps of continuous applicability, (2) steps that are repeated at intervals, and (3) time-dependent steps. Steps of continuous applicability, in text procedures, are usually formatted with an IF or a WHEN logic statement, depending upon the likelihood that the step would be executed at some point in the procedure. Steps that are repeated at intervals (i.e., recurrent steps) are generally stated with instructions to perform the step at timed intervals, such as every fifteen minutes. Time-dependent steps require operators to take an action at some point in the future; for example, an operator might be required to close a valve thirty minutes after opening it.

IF A AND B, OR C, THEN Perform D.
IF NOT, THEN Perform E.

Conditions:	A	Y	Y	Y	Y	N	N	N	N
	B	Y	Y	N	N	Y	Y	N	N
	C	Y	N	Y	N	Y	N	Y	N
Actions:		D	D	D	E	D	E	D	E

FIGURE 6.21. Decision Table Used to Represent Logic Statements

All of these steps can make EOPs difficult to follow. These steps are especially problematic in algorithmic flowcharts. The purpose of an algorithm is to structure a procedure so that discrete, simple decisions can be made in sequence. Steps that cannot be placed sequentially in the algorithm reduce the effectiveness of the algorithm as a decision aid. Further, as explained below, the graphic structure of an algorithmic flowchart makes it difficult to format such steps effectively.

Nonsequential steps should be clearly marked with one or more dissociative variable (position, size, or value) so that they can be easily found by operators. That is, the steps should always be located in the same place on the flowchart, or the symbols used for nonsequential steps should be large and dark. Position variation will typically be the most effective way of marking these steps. If all nonsequential steps that are applicable at any point in time are positioned together, operators will not need to search a procedure for them. For example, nonsequential steps could be placed in two different locations in the flowchart. Each step would be initially presented at the point in the procedure where it first applies. All nonsequential steps could be listed in a box in one corner of the flowchart sheet. Further, some sort of graphic element should indicate the applicability of the step. This element should allow an operator to easily find which nonsequential steps are applicable at any given point in the procedure. As is explained in Section 5.3.3, a large dark symbol that brackets other symbols in the flowchart can meet these needs in a big-picture flowchart.

Such a symbol would not work well in algorithmic flowcharts, however. Algorithmic flowcharts frequently continue through multiple columns on a page. This feature of the flowcharts make it difficult to include brackets to indicate when the nonsequential steps are applicable. If a nonsequential step applies only to primary or only to contingency actions, the bracketing problem is further compounded. If it is impossible to show the applicability of nonsequential steps graphically in a flowchart, then the steps should be repeated at relevant points in the flowchart.

So that operators can keep track of when time-dependent steps should be performed, the steps should include a space for operators to note the time that "starts the clock" or the time at which they must take the action. By noting these times, operators are more likely to remember to perform the action, and the operators' markings can function as a dissociative variable to draw attention to the step.

6.4.5 Equally Acceptable Steps

Nuclear power plants are designed with numerous redundant systems. If a given piece of hardware fails, an alternative piece of hardware often can be used. This means that various methods are available to perform a given task.

Presenting multiple alternatives when it is unnecessary to do so wastes space in flowcharts, however. If two options are equally acceptable, then only one should be presented. When there is a primary choice of actions, but there is some probability that those actions cannot be performed, the step should be formatted as a decision step that leads operators to an alternative set of actions if the primary method cannot be used.

6.4.6 Concurrent Steps

Concurrent steps are action steps that must be performed at the same time. Big-picture flowcharts make extensive use of concurrent steps; the basic idea behind the big-picture flowcharts is to show concurrent paths on the same page. Obviously, the number of different courses of action that must be taken at one time greatly affects the complexity of a procedure. As is explained in Section 6.3.3.3, the graphics of the flowchart will only provide a useful overview of the procedure if all concurrent paths are formatted so that they are readily visible.

In big-picture flowcharts which contain concurrently executed flowpaths the relative priorities of the flowpaths may change as operators progress through a procedure. The priority of a critical path should decrease after the parameter governed by that path has been brought to a relatively stable and acceptable condition. This is especially true if operators have been able to move smoothly and rapidly through that flowpath while the movement through other paths has been more problematic. Operators can, to some degree, make such judgments about path priorities by monitoring the entry conditions of each flowpath. If the concerns addressed in the entry conditions to a particular flowpath have been met, then that flowpath may be given a lower priority.

If concurrent steps are used liberally, as in big-picture flowcharts, hold points should be used as frequently as possible to allow operators to establish priorities among the different paths. Upon reaching a hold point, operators can disregard the remainder of that path and concentrate on other paths until the parameter specified in the hold point reaches a certain value.

Like nonsequential steps, concurrent steps violate the basic principles of algorithmic flowcharts. Performing tasks in multiple paths may force the operator to make multiple decisions simultaneously rather than move through the algorithm in a sequential manner. Therefore, the use of concurrent steps in algorithmic flowcharts should be avoided.

If it is necessary to use a concurrent path in an algorithmic flowchart, the text and graphics of the concurrent step structure should clearly indicate that the steps in <u>both</u> columns are to be performed rather than that a choice must be made between them, because such a format typically indicates an alternative structure. An action symbol should be used to introduce the concurrent paths, and text in this symbol should direct the operator to perform the following steps concurrently. As with all action symbols, a single flowline should enter the center of the top of this symbol, and a single flowline should exit from the center of the bottom of the symbol. The flowline should then branch to the two series of concurrent steps. The flowline should then re-converge into a single line below the concurrent steps, when the actions required are again sequential, as shown in Figure 6.22.

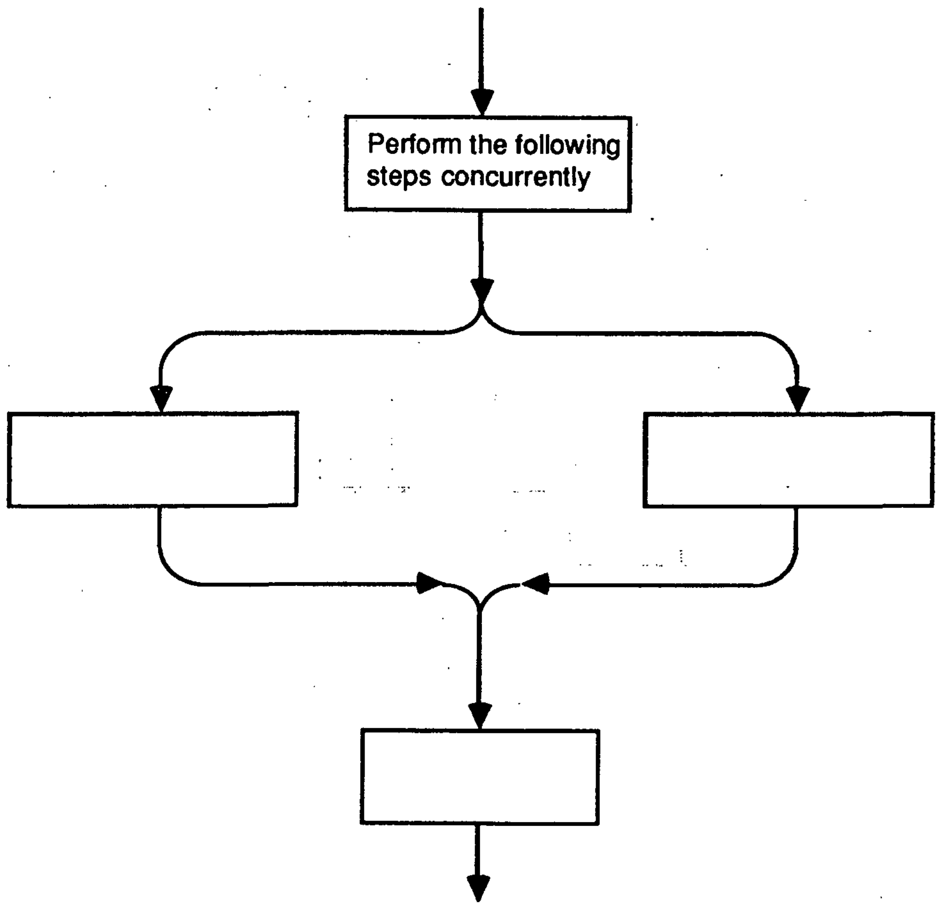

FIGURE 6.22. Concurrent Actions in an Algorithmic Flowchart

6.5 PRESENTING SUPPLEMENTAL INFORMATION IN FLOWCHARTS

In addition to decision and action steps, EOPs often require the presentation of information to supplement that presented in the decision and action steps. Four types of supplementary information are described in NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982): cautions, notes, figures, and tables. Because it is important during an emergency event that operators have easily available all of the information they need to respond to the event, these four types of supplementary information should be presented in a manner that provides operators with easy access to them. Techniques for presenting these types of supplementary information are discussed in this section.

6.5.1 Positioning Cautions and Notes

The most basic association in any flowchart is the set of items that make up a flowpath. All of these items form the association of information an operator needs to perform a task while moving through a flowpath. An obvious and graphically sound method of associating this information is to position all of the necessary information in the flowpath.

Many flowchart EOPs examined, however, did not include all relevant information directly within the flowpaths. In some flowcharts, cautions and notes were placed outside of the flowpaths. Numbers, placed in symbols or along the flowpaths, were used to direct the operators to these cautions and notes. The cautions and notes themselves were then all placed together at the edge of the flowchart sheet.

There are several significant disadvantages to positioning cautions and notes in this manner. Placing them outside of the flowpaths dissociates them from the steps to which they apply. Additionally, such positioning of cautions and notes increases the possibility that operators will not read them. Operators must direct their attention away from a flowpath to another area of the flowchart sheet, find the appropriate caution or note, read it, and then find their original place in the flowpath to continue. Operators may find this time-consuming and disruptive, and fail to search out the cautions or notes. If operators do go to the work of finding and reading the caution or note, the flow of information to the operator will be disrupted and he or she may encounter placekeeping difficulties. Operators may read the wrong caution or note, or they may return to the wrong flowpath or to the wrong place in the correct flowpath after reading a caution or note that is located out of the flowpath.

A flowchart designer interviewed for this report explained why this practice has evolved. He stated that the cautions and notes in some flowcharts occupy a significant amount of space, and therefore have a large visual impact on the flowchart. When placed in the flowpaths, the cautions and notes can determine much of the structure of the flowpaths and dominate how the flowpaths appear. He noted that a flowchart can best show the relationships among EOP steps (decisions and actions) if it is those steps that determine and dominate the appearance of the flowpaths, rather than the cautions or notes.

An examination of flowchart EOPs revealed another reason for placing cautions and notes outside of the flowpaths; such a format can save space on the flowchart sheet. Frequently, a single caution must be repeated several times in an EOP. If the caution is set outside of the flowpath and referenced by number, the caution statement need only be written out once.

Although it is important for EOP steps to determine the overall shape of a flowpath and for space constraints to play a role in flowchart design, it is too important that operators receive cautionary information in an accurate and timely manner to risk the errors that may occur if all cautions are placed outside of the flowpath. Consequently, it seems that cautions should be repeated in the flowpath as needed, unless the caution is so large that it destroys the unity of the flowpath. Further, the caution should be marked with a dissociative variable to emphasize its importance, as shown in Figure 6.23. It may be necessary to locate very large cautions outside of the flowpath and along the edge of the flowchart sheet, but this practice should be minimized to the extent possible.

It is conceivable, however, that the advantages of positioning notes outside of the flowpaths may outweigh the disadvantages of such placement. It may be acceptable to remove notes from the flowpath, for example, if an EOP contains many references to long notes, since the information notes contain is, by definition, less critical than that contained in cautions.

An alternative to placing all notes together on the edge of a flowchart sheet is to place each note to one side of a flowpath. This practice allows the flowpath structure to be more fully dictated by decision and action steps, and minimizes many of the usability problems inherent in placing notes on the edge of the flowchart sheet. Placing the note adjacent to the applicable step in the flowpath visually associates it with the step to which it applies. A dashed flowline connecting the note to the main flowpath could reduce placekeeping difficulties, as shown in Figure 6.24. The dashed texture of the line would usually indicate its lesser importance, compared to solid flowlines. This technique would not reduce the amount of space taken up by notes, however, as each note would still need to be written out in full every time it was required.

6.5.2 Presenting Figures and Tables

As noted in NUREG-0899 (USNRC, 1982), figures and tables are useful methods of condensing information and presenting it in text EOPs. Figures and tables are also likely to be necessary in flowcharts. Figures representing saturation curves and subcooling margins were often included in the flowchart EOPs examined for this project, as were tables representing lists of required valve positions.

In contrast to the preferred location of figures and tables in text EOPs, and the location of cautions and notes in flowcharts, figures and tables (other than decision tables) in flowcharts should not be placed near the steps to which they apply for several reasons. First, figures and tables are likely to be larger than action steps in a flowpath and so would inappropriately

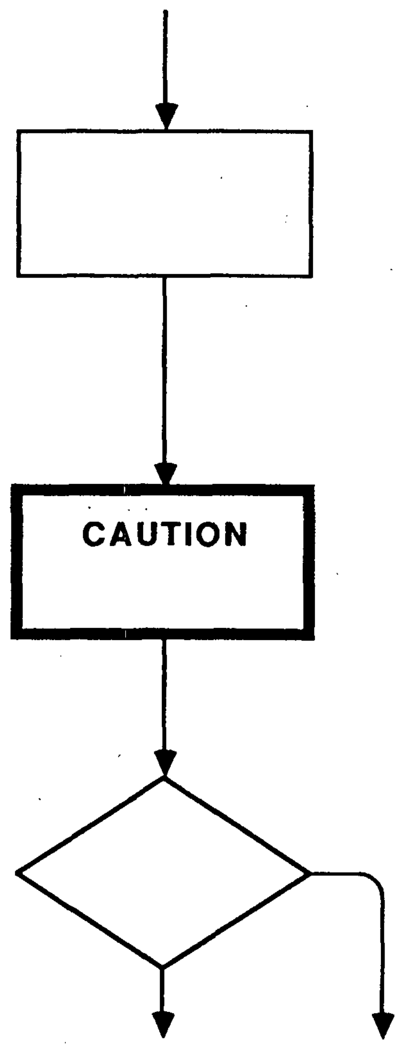

FIGURE 6.23. Caution Symbol

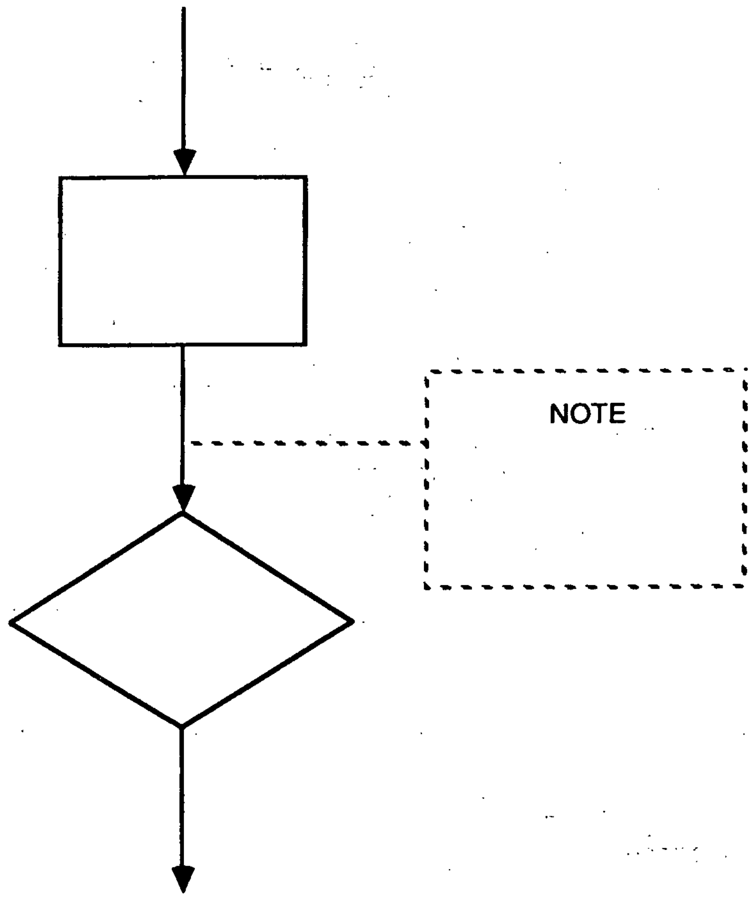

FIGURE 6.24. Note Placement

draw attention away from more important information. Second, they may obscure the flow of actions shown by the structure of the flowpath and so reduce the understandability of the flowchart. Third, the rectangular shapes that are necessary to enclose figures and tables and that indicate that the information in the figure or table is a unit could be confused with an action step or a decision table. Therefore, figures and tables should be placed outside of flowpaths in a consistent location on the flowchart sheet or presented as job performance aids, and referenced in the relevant action or decision steps.

Many of the principles of graphic design addressed here are applicable to the development of figures and tables for flowchart EOPs. A complete discussion of formatting techniques for figures and tables is beyond the scope of this report.

6.6 PLACEKEEPING

The confusion and uncertainty engendered in a control room by an emergency event may render following even the best-designed flowchart problematic. Although the flowchart layout should assist operators to track their progress through the procedure, providing operators with a placekeeping method can ease any difficulties they might experience in returning to a flowpath after reading a long note, figure, or table located on the edge of the flowchart sheet. A placekeeping method can also assist operators to coordinate their progress through concurrent flowpaths in big-picture flowcharts. Therefore, some means of placekeeping in both algorithmic and big-picture flowcharts is likely to be advantageous.

Two placekeeping techniques that are appropriate for text EOPs cannot be used as well in flowcharts. Adding check-off spaces to each step and numbering steps are methods frequently used to assist placekeeping in text EOPs. Both of these conventions, however, would clutter the already visually complex image of the flowchart. Further, check-off spaces would be of only limited value in a flowchart with many loops. In a series of steps that may be repeated, the fact that a step has been checked-off does not necessarily mean that the step will not be performed again. Steps ahead of an operator's current location could be checked off as a result of his prior activities when he encounters them in the next iteration through the loop, which could be very confusing if the steps are must be repeated.

An alternative placekeeping technique that is more useful with flowchart EOPs is to laminate the flowcharts so that operators can mark the steps they have performed with a grease pencil. It would be easy to erase (wipe off) placekeeping notations that no longer applied when the operator was required to repeat a series of steps, and the operator could provide his own emphasis to important information without permanently adding clutter to the flowcharts. Further, the implied movement provided by the graphics of the flowchart would be significantly reinforced by the operator's own markings.

Another placekeeping technique that can be used with flowcharts is to mount them on a metal surface and then use magnetized pawns to mark the operator's current step location in each flowpath. Dark value, color, or size could be used to make the pawns stand out when placed on the flowchart sheet.

6.7 SUMMARY: THE FLOWCHART LAYOUT PROCESS

One of the most difficult tasks facing the flowchart designer is to lay out the overall structure of the flowchart so that the sequence of actions and decisions presented in the flowchart and their interrelationships are obvious from the graphics of the flowchart. Finding the best flowchart layout will require experimentation and is likely to be an iterative process.

The flowchart designer's first step in this process is to review the technical guidelines provided by the relevant owners' group and the plant-specific technical guidelines that should have been developed for the EOPs currently in use. These guidelines will describe how many of the actions and decisions in flowchart EOPs must be sequenced.

The designer will also need to review any documents that describe how the plant-specific technical guidelines differ from the owners' group guidelines. In some cases, the differences will reflect unique characteristics of plant hardware that must be incorporated into the flowchart EOPs. In other cases, these differences may reflect the preferences of the individuals who initially developed the text EOPs or the preferences of operators who have used them. Where technical necessity is not the source of the differences, the flowchart designer may alter step sequences to be compatible with the flowchart format.

Once the step sequences have been determined, the flowchart designer can experiment with various arrangements of the eight basic flowchart structures to arrive at the layout that best shows the organization of the procedure. Using a top-to-bottom primary direction of movement and a left-to-right secondary direction of movement through the flowchart will create main flowpaths that fall into columns with contingency actions located to the right. Alternative locations for column and page breaks should also be examined, if such breaks in the flowpath will be necessary to present a long procedure.

Finally, when the overall arrangement of symbols in the flowchart has been determined, the flowchart designer can begin to focus on presenting individual units of information in the flowchart. Techniques for presenting individual decision and action steps should be considered (e.g., should a series of decisions be presented in a decision table or with basic structures?) at this point, as well as the incorporation of cautions, notes, figures, tables, and methods of placekeeping.

7.0 PRESENTING TEXT IN FLOWCHART EOPs

As has been discussed in the preceding sections of this report, the graphics of the flowchart can convey a great deal of information to operators. However, the bulk of information in a flowchart is not presented graphically; it must be conveyed through text. Therefore, the manner in which text is presented in flowcharts also requires the flowchart designer's attention.

The readability of text is fundamentally a function of the contrast between the letter and the surface on which the letter is printed (Smith, 1979). Contrast, which is the result of value variations in this instance, is discussed in Section 4.1 of this report. Given adequate contrast, text readability is affected by four factors: (1) the size of the type, (2) whether the type is in all capitals or mixed case, (3) the type font that is used, and (4) how the text is justified.

7.1 TYPE SIZE

The type in a flowchart must be large enough so that it can be read from an appropriate distance. For example, if a flowchart is mounted on a wall above a horizontal control panel, the type should be readable by an operator without the operator being required to lean over the horizontal panel. In other words, if the panel extends 20 inches horizontally from the vertical surface on which the flowchart is mounted, the type should be readable at a distance of at least 20 inches, assuming the flowchart is at eye level. Similarly, if the flowchart is spread out on a table, the type should be readable standing or leaning slightly over the table.

Appropriate type size is determined by considering the visual angle created by the viewer's eye and the top and bottom of a letter, as shown in Figure 7.1. Visual angle is given by the following formula:

$$V = (3438)(L/D).$$

In this formula, L is the height of the object (in this instance, the height of the letter); D is the distance from the observer's eye to the object; and V is the visual angle, expressed in minutes of arc.

Estimates of the necessary visual angle vary. Because the smallest visual angle that the eye can detect is 1 minute, a letter such as an "E" must subtend at least 5 minutes. Each of the horizontal strokes must subtend at least 1 minute or the eye will not discern it, and the spaces between the strokes must subtend at least 1 minute or the eye will not be able to separate the strokes.

Such minimum figures are impractical in actual use. Estimates of usable visual angles for various lighting conditions range from 10 minutes to 37 minutes (Smith, 1979). Assuming Bailey's (1982) values of 15 minutes for

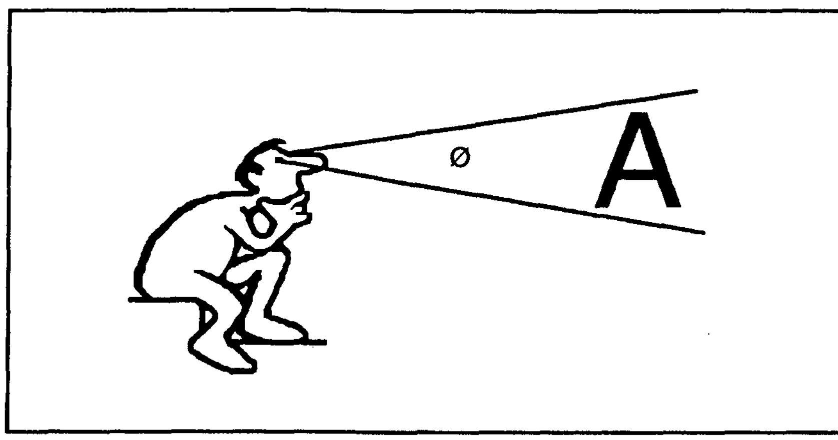

FIGURE 7.1. Visual Angle (Ø)

good lighting and 21 minutes for poor lighting, which seem to be reasonable averages, the previous formula can be arranged to give the correct type height at a particular reading distance.

$$L_o = 0.0044D$$
$$L_d = 0.0061D.$$

L_o is the minimum type height in optimal lighting; L_d is the minimal type height in degraded lighting. Both L_o and L_d are expressed in inches.

This formula gives type height, which is not the same as type size. Type size is usually measured in points[1] and is the distance from the bottom of a descender (a letter such as "y") to the top of an ascender (a letter such as "I"). Thus, few, if any, letters in 9-point type span a full 9-point vertical distance and the angle actually subtended by the letters will be smaller than that assumed in the formulas for L_o and L_d.

This discrepancy is further aggravated by another typesetting practice: in traditional typesetting, the size of the type is the size of the block of lead in which the type character is cast. The block of lead may be taller than the height between the top of an ascender and the bottom of a descender. In other words, 9-point type is cast in a block of lead that is 9 points tall, but the ascenders may not touch the top of the block and the descenders may not touch the bottom of the block; see Figure 7.2. Blocks of type can then be "set solid" to form a page without the ascenders and descenders on adjacent lines touching.

One of the flowchart designers interviewed for this project expressed another concern that should be taken into account when determining type size. He stated that, when reading a flowchart at the back of the control room, he was required frequently to shift his attention from the flowchart to a distant control panel, and that his eyes had trouble making the adjustment. For this reason, flowchart designers should consider using a larger type size than that specified by this formula if operators will be required to frequently look at distant panels.

In summary, typography has long been more of an art than a science, and type size, as traditionally defined, is a notoriously vague measure of readability. It is important to measure the minimum height of the shortest letter, such as a lower-case "a" (if lower case is used), and not simply use the type size, which may be much larger than minimum letter height.

7.2 TYPE CASE

Text in a flowchart can be written in all capitals, or in mixed case, where words are capitalized according to standard English usage (that is, proper nouns and the first letter of each sentence are capitalized). There are advantages to each approach: capital letters are larger and can be read at a

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[1]There are approximately 72 points in an inch.

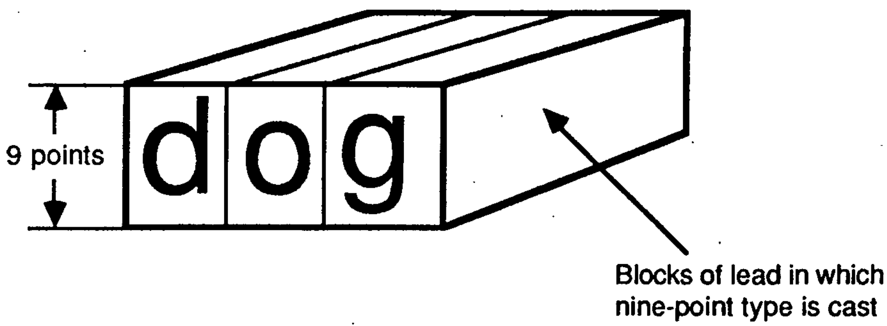

FIGURE 7.2. Size of Block of Type Versus Size of Letter

greater distance, while lower-case letters are more distinct because there is a greater variation in their size and shape.

The literature indicates that, when not appearing in a block of text, words printed in all capitals are easier to read. Kinney and Showman (1967) found that "for applications other than standard printing, upper-case letters are preferred," and that "common words seen in isolation are recognized more quickly when printed in all upper-case letters." Vartabedian (1971) found that, when searching a list of words shown on a cathode ray tube for a specific word, subjects located the specific word 13 percent faster when the words were presented in all capital letters. Vartabedian presented 27 words on a screen, with sufficient space between them that the words did not appear as a block of text.

However, the literature also indicates that blocks of text are more easily read when presented in mixed case. For example, this report would be very difficult to read if printed in all upper case.

The classic study in this area was conducted by Tinker and Patterson in 1928. They gave subjects a standard speed-reading test, consisting of several paragraphs, set in either all capitals, lower case (apparently mixed case), or italics. They found that "the subjects read 4.74 words per second of the all capitals text and 5.38 words per second of the lower case text" (p. 364). They attributed this difference to three factors:

> (1) The space covered by the text printed in all capitals was 35 percent greater than for the same material in lower-case letters. This alone would tend to slow up the reading of all capitals for the number of fixational pauses is increased when the same material is spread over a greater distance.... (2) The total word form is more characteristic with words printed in lower case letters than with those printed in all capitals. Many studies have demonstrated that total word form is an important factor in the perception of words.... (3) The reading of the ordinary individual is concerned largely with material set in lower-case type. This [study] emphasizes the fact that material printed in all capitals produces a less familiar reading situation and therefore undoubtedly slows up reading somewhat. (pp. 366-367)

In a later study, Tinker (1955) reached similar conclusions, finding that, in a prolonged reading task, text written in all capitals was read from 10.2 to 14.2 percent slower than mixed case. Tinker stated that "the retarding effect of all-capital print is relatively large. In fact, few typographical variations in printing practice produce variations as large as this" (p. 444). Another study (Poulton and Brown, 1968) found that text typed in mixed case was read 13 percent faster than text typed in all uppercase.

The key difference here is that Kinney and Showman and Vartabedian presented subjects with isolated words, while Tinker and Patterson, Tinker, and Poulton and Brown presented subjects with blocks of text. The applicability of these studies to flowcharts thus depends on the amount of text that is being presented. What constitutes a block of text? A short step contained within a diamond-shaped symbol certainly does not. A long note certainly does. The boundary--that is, the point at which text becomes a block--is not clearly defined.

If long blocks of text are included in a flowchart, that text should be printed in mixed case. For shorter steps, the flowchart designer faces a trade-off: mixed case may be easier to read, but a flowchart using mixed case will be larger because the type size must be larger so that the lower-case letters subtend a sufficient visual angle.

The flowchart designers interviewed indicated that the decision on which type case to use was often based on the capabilities of their printers: most flowcharts are produced on graphics plotters, some of which do not print lower-case letters, or print lower-case letters that are compressed and very difficult to read. If they were not constrained by their plotter, the interviewees chose the type case that "looked the best."

Because of the many variables that enter into a decision regarding type case, using what "looks best" is generally the best technique. However, the smallest letter used should subtend a sufficient visual angle, and blocks of text should not be presented in all capital letters.

7.3 FONT

A specific type face is referred to as a "font." Three important characteristics of type are (1) whether the font is serif or sans serif, (2) whether the type face is bold, and (3) whether the type face is italic.

7.3.1 Serif Versus Sans Serif

Fonts are broadly classified into one of two categories: serif and sans serif. Serifs are small strokes at the end of the main strokes of letters; for example, at the top of an "l." A font that includes serifs is called a serif typeface; a font without them is called a sans serif typeface. The type in this report is sans serif. Serif type is generally used in novels and newspapers.

The literature on the readability of serif type versus sans serif type is inconclusive. When deciding on the correct typeface to use in a flowchart, a designer will most likely be constrained by the plotter used: most plotters print in a simpler, sans serif typeface. Because the size of the type in a flowchart is often near the lower end of the legibility scale, simpler type faces might be easier to read. Thus, sans serif type should be used in flowcharts; however, a serif typeface of sufficient size should not present readability problems.

In plants where a dot matrix printer is used, particular attention should be paid to the quality of the type. Only dot matrix printers that produce near letter-quality output should be used, and care should be taken to see that the type quality remains high; the ribbon should be changed and the printer head should be cleaned frequently.

7.3.2 Italics

Italics, or slanted letters, technically are not a font in themselves, but are a variation on a font. In other words, Helvetica and Helvetica Italic are the same font.

Italic text is more difficult to read than standard type. Tinker and Patterson (1928) found that students read 5.22 words per minute of mixed case, and only 5.08 words per minute of italics. In a later study, Tinker (1955) found that italics were read 4.2 to 6.3 percent slower than mixed case. Because these readability problems would likely be aggravated by the small type used in flowcharts, italics should not be used in flowcharts.

7.3.3 Bold Type

Like italics, bold type is technically a variation of a font rather than a font in itself. The wider lines in bold type can make it difficult to read, especially if the type is small, because the eye will have trouble discerning the strokes. For example, if an "E" were printed in bold type, the distance between the now-wider horizontal strokes may, at the given reading distance, subtend less than the 1 minute of arc that the eye is capable of discerning. On the other hand, a particularly faint type of a small size may be difficult to read because the strokes do not subtend a sufficient visual angle; in this instance, bold type would be more legible. However, because bolding text would compete with other graphic cues in a flowchart and because other graphic techniques can be used to emphasize the information contained in a flowchart symbol, bold text should not be used in flowchart EOPs.

7.4 JUSTIFICATION

There are two ways in which text in a rectangular box, such as an action symbol, can be formatted to create rectangular boxes of text. Text can be set ragged right (i.e., with lines of different lengths, as in this report), or flush right (i.e., with lines of equal lengths). Text that is set flush right is called "justified" text.

Justified text is created by adding extra spaces between words on short lines so that all lines of text equal the length of the longest line. Justified text is easiest to read when the text lines are long, because the extra spaces required can be distributed throughout the line and long gaps between words can be avoided.

For short lines of text such as those used in flowcharts, however, large gaps can occur when text is justified. Because these large gaps disrupt the flow of information in a short line of text, Turnbull and Baird (1980) recommend that ragged-right justification be used for short blocks of text. Therefore, ragged-right justification should be used for the text enclosed in flowchart symbols to improve its readability.

7.5 CONCLUSIONS

Among the factors that affect the readability of type, the contrast between the letters on the flowchart page and the white space that surrounds them is the most important. The four other factors that affect the readability of text are type size (letter height), type case, font, and justification. These four factors are interrelated and are related to the conditions in which the text will be read. When designing the text in a flowchart, the flowchart designer must consider the distance from which the flowchart will be read and the likelihood that the lighting conditions in the control room will be degraded during an emergency event.

8.0 APPLYING THE PGP TO FLOWCHART EOPs

The flowchart designer's task does not end with the preparation of a set of flowchart-format EOPs. Several other issues should be addressed before the flowchart EOPs are implemented. Just as it is important for text EOPs to be verified and validated, flowchart EOPs should be verified and validated to ensure that they are usable and accurate. Operators should also be trained whenever revised EOPs are implemented at a plant. Validation, verification, and training are especially important for licensees using flowchart EOPs because of the unique format of flowcharts, the lower level of detail typically found in flowcharts, and the problems that may occur when operators use several large flowcharts concurrently. In addition, a change to flowchart EOPs will mean that a new EOP writers' guide should be prepared to ensure that flowchart designers are consistent and follow important human factors and graphics principles in the flowchart EOPs that they design. Further, the new flowchart EOPs may need revision to address any problems that are discovered during validation, verification, and training.

Section 8.1 describes the validation and verification techniques that should be used for flowchart EOPs. Section 8.2 discusses programs for training operators on EOPs. Section 8.3 discusses the revisions that will be necessary to the licensee's writers' guide to address flowchart EOPs. Section 8.4 discusses the production and revision of flowchart EOPs. Although these sections emphasize flowchart EOPs, the information they contain is derived from NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982), and so applies to text EOPs as well.

8.1 VALIDATION AND VERIFICATION

The NRC has required licensees to submit for review a description of the plan that they will follow when validating and verifying EOPs (USNRC Generic Letter No. 82-33; December 1982). This plan is part of the licensee's procedures generation package (PGP), which also includes plant-specific technical guidelines, a procedure writers' guide, and a training program description (NUREG-0899, USNRC, 1982).

Some licensees distinguish validation from verification in their PGPs; others do not. For the purposes of this report, validation can be defined as the process followed to determine if flowchart EOPs are usable. Validation methods include simulator exercises and EOP walk-throughs. A validation program should have the objectives of ensuring that (NUREG-0899, USNRC, 1982, p. 10):

- There is a high level of assurance that the procedures will work; i.e., the procedures guide the operator in mitigating transients and accidents;
- The EOPs are usable; i.e., they can be followed without confusion, delays, errors, etc.; and

- The language and level of information presented in the EOPs are compatible with the minimum number, qualifications, training, and experience of the operating staff.

Verification can be defined as the process used to determine if the EOPs are technically accurate. Verification methods include EOP walk-throughs, table-top reviews, and operating team reviews. A verification program should have the objectives of ensuring that (USNRC, 1982, p. 10):

- The EOPs are technically correct; i.e., they accurately reflect the technical guidelines;

- There is a correspondence between the procedures and control room/plant hardware; i.e., controls, equipment, and indications that are referenced in the EOPs are available (inside and outside the control room), use the same designations, use the same units of measurement, and operate as specified in the procedures; and

- The EOPs are written correctly; i.e., they accurately reflect the plant-specific writers' guide.

The remainder of this section discusses specific elements of the validation and verification processes. Sections 8.1.1 and 8.1.2 discuss methods of validation and verification in greater detail. Section 8.1.3 discusses specific problems that may arise during the execution of flowchart EOPs and thus deserve special attention during validation and verification.

8.1.1 Methods of Validation

In order to validate, or assess the usability of, flowchart EOPs, operating crews should execute and walk through the procedures. Ideally, operators would validate the EOPs on a plant-specific simulator. Because many licensees do not yet have plant-specific simulators, EOPs are often validated on generic simulators. If a generic simulator is used, the EOPs should be re-validated on a plant-specific simulator when one becomes available. Regardless of the type of simulator used, the simulator should be the primary method of validation.

All EOPs should also be validated with walk-throughs of the procedures. These walk-throughs are intended to address any differences between the plant and the simulator. For example, the plant control room might be smaller than the simulator and thus not provide adequate room to use multiple flowcharts. Walk-throughs are also important in those situations where a plant-specific simulator does not behave in the same manner as the plant. Further, walking through the EOPs at the plant allows validation of actions performed outside of the control room.

Selection of simulator scenarios is an important aspect of validation. Although the NRC does not require licensees to submit specific scenarios in their PGPs, licensees should carefully consider the criteria that they will use when developing the validation scenarios. One important criterion is that the scenarios should address single, sequential-multiple, and simultaneous-multiple failures.

Various types of personnel should be involved in the validation exercises. A minimum shift operating crew (as defined in the plant's technical specifications) that includes personnel with varying levels of experience should execute the scenarios both in the simulator and during walk-throughs. Operators should be observed while performing the procedures by technical experts, flowchart designers, and human factors experts.

The validation process should include a formal means for incorporating feedback. It is especially important that flowchart designers be involved in validation, so that the feedback from operators about any usability problems they encounter in the flowcharts is as direct as possible. When considering feedback from operators, flowchart designers should keep in mind that operators are the audience for EOPs and that EOPs should be written to conform to their needs.

8.1.2 Methods of Verification

EOPs are verified, or determined to be technically accurate, during simulator exercises, table-top reviews, and walk-throughs. It is important that the personnel involved in verifying the flowchart EOPs be different from the personnel who have been responsible for developing them. Aspects of the flowcharts that are obvious to the flowchart designer (e.g., the meanings of symbols, the nomenclature used) are likely to be less so to individuals who are not as familiar with the procedures. Independent verification can uncover significant deficiencies in the flowcharts that have not been identified by the flowchart designer.

Table-top technical verification should be conducted by operators and technical experts. These personnel should be instructed to review all EOPs to assess the technical accuracy of the procedures by comparing them to the owners' group and plant-specific technical guidelines. All differences between the technical guidelines and the EOPs should be evaluated for safety significance. Those differences that may be safety significant should receive special attention.

The correspondence between EOPs and the displays and controls inside and outside of the control room should be verified during walk-throughs. Because a plant-specific simulator may vary subtly from the actual control room (e.g., panel markings may differ), walk-throughs should be conducted in the actual control room rather than in the simulator. In multi-unit sites, walk-throughs should be conducted separately in each unit.

EOPs should also be verified by human factors experts to ensure that they are written in accordance with the licensee's writers' guide. This aspect of verification should consist of a table-top review during which the flowcharts are compared to the requirements of the writers' guide. Checklists that summarize the requirements of the writers' guide may be useful in verifying each EOP.

As with validation, verification should incorporate a feedback mechanism so that any problems with the content of the procedures is brought to the attention of the flowchart designers. This mechanism should provide for the formal resolution of concerns.

8.1.3 Areas of Concern During the Validation and Verification of Flowchart EOPs

During validation and verification of flowchart EOPs, particular attention should be paid to those aspects of the EOPs that might be problematic. These aspects include the level of detail in the flowcharts, difficulties in the physical use of the flowcharts, and requirements for concurrent execution of multiple EOPs on different flowcharts.

8.1.3.1 Level of Detail

As discussed in Section 3.3, the level of detail is often reduced in flowchart EOPs. During validation, human factors experts should pay attention to the ease with which newly certified operators can execute the procedures so that the usability of the flowcharts for less experienced operators is assured. It may also be helpful to have a less experienced operator act as the procedure reader during validation.

8.1.3.2 Physical Use

Large flowcharts can be physically difficult to manage. During simulator exercises and control room walk-throughs, human factors experts should pay particular attention to the ease with which operators can physically interact with the flowcharts.

Operators should be provided with a flat surface on which they can lay large flowcharts so as not to interfere with seeing and manipulating instruments and controls. Space for laying out only one flowchart is likely to be insufficient, because operators may use many flowcharts at once during an emergency event. Operators may use as many as four or five flowcharts simultaneously, particularly if the flowcharts are of the big-picture type.

The big-picture flowcharts examined during the preparation of this report varied widely in size from plant to plant, the largest being about 50 inches long by 36 inches high. Personnel using six of these flowcharts would require nearly 75 square feet of usable lay-down space--either a table 25 feet by 3 feet, on which the flowcharts could be laid end to end, or a table 12 feet by 6 feet, on which the charts could be laid two deep. Most control rooms do not include enough space for such a large table. Even if space was available, the flowcharts would be so spread out that they would be difficult to use, because an operator executing two (or more) concurrent paths that were on widely separated flowcharts would not be able to read both paths from one place. Consequently, operators typically stack the flowcharts on a table and shuffle through them, "like a deck of cards, "as one flowchart designer interviewed for this project described it. To assess problems of physical use that might arise, validation should include scenarios that require operators to follow multiple flowcharts.

The use of large flowcharts also requires the reader to remain stationed at a back table or easel, and to be farther from the operators. Human factors experts should watch for any difficulties in communication between the reader and the operators that might arise due to the distance between them. Interviewees indicated that a properly trained control room staff should not experience communication difficulties and, if such difficulties were to arise, it would indicate a problem in training or control room design (for example, the procedure table would be too far from the control boards or the ambient noise level would be too high).

8.1.3.3 Execution of Concurrent Procedures

Establishing priorities between the concurrent procedures found in big-picture flowcharts can place a significant burden on operator training. During validation, human factors experts should watch for difficulties that operators may experience in establishing priorities between flowpaths, such as operators developing "tunnel vision" on one path and ignoring others. If difficulties arise, flowchart designers should consider means of improving the flowcharts to reduce the problem, such as incorporating hold points into the paths, incorporating notes that remind operators to monitor other paths, or improving placekeeping methods. Further, scenarios should be developed specifically to address the problem of tunnel vision. For example, a scenario could begin with presenting a single problem to the operators. Once the operators were occupied with this problem, a second problem could be introduced.

8.2 TRAINING OPERATORS TO USE FLOWCHART EOPs

In their PGPs, licensees also submit a description of the program that will be used to train operators on revisions to EOPs. This training program should have the following objectives (USNRC, 1985, p. A15):

- Trainees should understand the philosophy behind the approach to EOPs; i.e., their structure and approach to transient and accident mitigation, including control of safety functions, accident evaluation and diagnosis and the achievement of safe, stable or shutdown conditions;

- Trainees should understand the mitigation strategy and technical basis of the EOPs; i.e., the function and use of plant systems, subsystems, and components in mitigating transients and accidents;

- Trainees should have a working knowledge of the technical content of EOPs; i.e., they must understand and know how to perform each step in all EOPs to achieve EOP objectives; and

- Trainees must be capable of executing the EOPs (as individuals and teams) under operational conditions; i.e., they must be able to carry out an EOP successfully during transients and accidents.

Operator training on flowchart EOPs should consist of classroom instruction, followed by simulator exercises and procedure walk-throughs. Classroom instruction for flowchart EOPs should meet the objectives listed above and should also address the conventions used to present information in the flowcharts. For example, the acronyms and abbreviations used in the EOPs should be discussed as well as the meanings of the different types of symbols used (Barnes and Radford, 1986). During simulator exercises, a typical crew of operators should respond to a wide variety of scenarios, including single, sequential-multiple, and simultaneous-multiple failures. All operators should be trained as teams and should assume the roles they would be expected to take in an actual emergency. Operators also should walk through all EOPs if a generic simulator is used and, if a plant-specific simulator is used, walk-throughs should be used in those situations where the simulator does not respond in the same manner as the plant. Walk-throughs are not a substitute for simulator exercises.

At the end of training, operators should be evaluated to ensure that their knowledge of the EOPs meets the objectives of the training. Further, all operators should be trained on the current revisions of all EOPs before going on shift.

During training, licensees should emphasize those aspects of flowchart EOPs that are likely to be problematic. Operators using big-picture flowcharts should be trained to execute and establish priorities between concurrent flowpaths. Training should also compensate for the lower level of detail likely to be used in flowcharts.

8.3 REVISIONS TO THE WRITERS' GUIDE

Because most licensees' writers' guides were developed to describe the preparation of text procedures, it is important for licensees to revise their writers' guides to address flowchart-format EOPs. Specific guidance for flowchart designers, if followed, will ensure that all EOPs in the set and any future revisions to the flowcharts are consistent in terms of the conventions used. A detailed writers' guide can also help to ensure that important human factors and graphic design principles are incorporated into the flowchart EOPs. The information presented in Volume 1 of this report can provide a technical basis for the revised writers' guide and Volume 2 may be helpful as a basic model.

8.4 PRODUCTION AND REVISION

Revisions to the flowchart EOPs may be necessary to address any deficiencies that are revealed during validation, verification, and training. In addition, design changes and equipment modifications over the life of the plant will also require changes to the EOPs. Because flowchart EOPs are generally more complicated to produce and revise than text procedures, licensees using flowcharts must have access to special personnel and production capabilities that are not required for text procedures.

In addition to the usual personnel involved in preparing procedures (i.e., experts in plant operations, engineering, and human factors or technical writing), licensees using flowcharts should also employ or contract with draftspersons, graphic artists, or consultants who have experience with the graphic presentation of information. Computer drafting experience may also be necessary.

Flowchart EOPs will be prepared and duplicated differently from text procedures. Because flowcharts cannot be drawn on the word processors or typewriters used to prepare text procedures, graphic designers may be required to produce the flowcharts by hand or computer software and high-quality printers may be necessary. Further, large flowcharts cannot be duplicated on office copy machines.

Temporary changes to flowchart EOPs are also problematic. One flowchart designer interviewed taped temporary changes to the flowchart while another re-laminated the existing flowchart to incorporate each temporary change. They noted that neither of these techniques were satisfactory because the changes cluttered the flowchart page and graphically drew unwarranted attention. Consequently, even a simple change may necessitate that the entire flowchart be re-drawn. In a text procedure, it may be necessary to re-type only a single page (Fisher, 1966).

Because flowcharts involve both text and graphics, flowcharts will generally be more difficult to produce, revise, and duplicate than procedures that include only text. For these reasons, plant personnel might be more hesitant to make necessary revisions to a flowchart than to a text EOP (Morgenstern et al., 1987). Consequently, document production and revision processes should be upgraded in plants where flowchart EOPs are used so that high-quality flowcharts can be produced as needed.

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APPENDIX A

FLOWCHART EOP EVALUATION CHECKLIST

FLOWCHART EOP EVALUATION CHECKLIST

Evaluation Criteria	Yes	No	Example Location
1.0 Layout			
1.1 Organization of EOP apparent in the layout			
1.2 Minimal graphic clutter from step grouping techniques			
1.3 Upper-level steps and substeps			
1.3.1 Not used in algorithmic flowcharts			
1.3.2 Not used or presented together in a divided box in big-picture flowcharts			
1.4 Flowlines that contain no symbols (loops and alternative bypasses) frame repeated or bypassed steps			
1.5 Adequate white space between flowpaths .			
1.6 Overall movement top-to-bottom and left-to-right			
1.7 Clear column structure			
1.8 Branching horizontal paths minimized . .			
1.9 No right-to-left series of three or more symbols			
1.10 No bottom-to-top series of three or more symbols			
1.11 All text is read left-to-right			
1.12 In algorithmic flowcharts, steps relevant to expected responses move straight down the page with contingency actions to the right of this column and looping flowlines to the left			

Evaluation Criteria	Yes	No	Example Location
1.13 In big-picture flowcharts, flowlines separated with white space from the dark lines of override steps			
1.14 Flowlines have arrows			
1.15 Minimal turns in flowlines			
1.16 Rounded corners on flowlines and lines join tangentially			
1.17 Flowlines generally kept short			
1.18 Long parallel lines leading to same symbol merged			
2.0 Symbols			
2.1 No more than 7-9 different symbols used .			
2.2 Symbol shapes distinctive and appropriate, such as the following:			
2.2.1 Diamond or diamond/rectangle shape for decision steps			
2.2.2 Rectangle for action steps . . .			
2.2.3 Large dark symbol for override steps with vertical lines that bracket relevant steps			
3.0 Referencing and Branching			
3.1 Indicated with flowlines whenever possible			
3.2 Connector symbols used to avoid crossing of lines			
3.3 Exit connector symbol identifies type of cross-reference (e.g., "GO TO" for branch, "CONCURRENTLY PERFORM" for reference, and "CONTINUE AT" for page break)			

Evaluation Criteria	Yes	No	Example Location
3.4 Exit connector symbol identifies location of entry connector symbol by procedure, page number, grid coordinates and letter code			
3.5 Each entry connector symbol fully corresponds to an exit connector symbol .			
4.0 Column and Page Breaks			
4.1 Column breaks minimized			
4.2 Minimum number of flowlines interrupted .			
4.3 Breaks do not fall within logical unit of information (e.g., a step)			
4.4 Column transitions move left-to-right .			
4.5 In big-picture flowcharts, subsequent columns of a multi-column flowpath do not look like additional separate flowpaths to be performed concurrently			
4.6 No page breaks in bit-picture flowcharts.			
5.0 Entry conditions in upper left or upper center of the flow chart			
6.0 Decision Steps			
6.1 Usually presented with decision symbols (understandable decision tables are okay) in algorithmic flowcharts			
6.2 Not presented with logic terms in algorithmic flowcharts			
6.3 One format (logic terms or decision tables) is relied upon and decision symbols are minimized in big-picture flowcharts			
7.0 Action Steps			
7.1 One action or two closely related actions per symbol			

Evaluation Criteria	Yes	No	Example Location
7.2 Stated in imperative mode			
8.0 Nonsequential Steps (includes concurrent and time-dependent steps)			
8.1 Presented in symbol that brackets relevant steps in big-picture flowcharts . . .			
8.2 Text indicates applicability of step . .			
8.3 Space provided for operator notations if required (e.g., in time-dependent steps).			
9.0 Recurrent Steps			
9.1 Recurrent steps are repeated in flowpath as necessary in algorithmic flowcharts .			
9.2 Recurrent steps are formatted as override steps in big-picture flowcharts . . .			
10.0 Concurrent Steps			
10.1 Presented as parallel flowpaths that branch out of an action symbol or entry symbol			
10.2 Action symbol or decision symbol at beginning of concurrent paths includes instructions that both paths are to be performed concurrently			
11.0 Equally Acceptable Steps			
11.1 Avoided			
11.2 Formatted as decision step when present .			
12.0 Holds points formatted as WHEN, THEN or WAIT UNTIL statements in octagonal symbol			
13.0 Cautions and Notes			
13.1 Cautions and notes always before relevant steps			

Evaluation Criteria	Yes	No	Example Location
13.2 Cautions and notes are placed in flowpath directly before first relevant step unless large size of caution or note significantly damages the unity of the flowpath			
13.3 Cautions that are not placed directly in flowpaths are easy to find			
13.4 Notes that are not placed directly in flowpaths are placed to the left of vertical paths or above horizontal paths and connected to paths with dashed lines.			
13.5 No actions in cautions or notes . . .			
13.6 Cautions emphasized and with dissociative variation such as a dark border around symbol			
14.0 Level-of-Detail			
14.1 Operators are not required to use standard text procedures or other manuals or drawings to supplement lack of detail in flowcharts			
14.2 If technical detail in flowcharts is minimal, flowcharts direct operators to use JPAs			
15.0 Emphasis Techniques			
15.1 Graphic techniques			
15.1.1 Prominent positioning, large size, dark value, and/or surrounding white space used to emphasize cautions, entry points, and nonsequential steps			
15.1.2 Color (if used) used sparingly and consistently			
15.1.3 Colors contrast with background or each other			

Evaluation Criteria	Yes	No	Example Location
15.1.4 All lines black or bright red .			
15.1.5 If color is used for showing an order series, the series of cool colors is used, or the series of warm colors is used			
15.2 Text techniques			
15.2.1 Logic terms, the words "CAUTION" and "NOTE" in the headings of cautions and notes, and cross-referencing terms (e.g., "GO TO," "CONCURRENTLY PERFORM," AND "CONTINUE AT") are fully capitalized			
15.2.2 Underlining, italics and bold print not used			
16.0 Style of Expression			
16.1 Terminology			
16.1.1 Short, common, and concrete terms.			
16.1.2 Infrequently used equipment identified completely			
16.1.3 No vague adverbs			
16.1.4 Terms and meanings used consistently			
16.2 Sentence structure and punctuation			
16.2.1 Complete but concise sentences .			
16.2.2 Punctuation conforms to standard American English (final punctuation marks may be omitted in sentences that require no internal punctuation)			

Evaluation Criteria	Yes	No	Example Location
17.0 Figures and Tables			
17.1 Legible			
17.2 Standard graphic practices used . . .			
18.0 Complete location information provided for hard-to-find equipment and controls			
19.0 Flowchart Identification Information			
19.1 Identification information is placed in a box, which is placed in the same prominent location on each flowchart sheet . . .			
19.2 Procedure title and number			
19.3 Revision number			
19.4 Revision date			
19.5 Facility designation			
19.6 Unit designation, if applicable . . .			
20.0 Placekeeping			
20.1 Method available			
20.2 Placekeeping aids do not clutter the flowchart			
20.3 Operators not required to perform calculations without assistance . . .			

APPENDIX B

PROTOCOL FOR SITE VISITS

PROTOCOL FOR SITE VISITS

What has led to your involvement and your clients' interests in flowchart EOPs?

Have you also been involved in preparing text EOPs for plants?

What type of staff persons do you have involved in developing flowcharts for plants (e.g., human factors types, engineers, ROs, SROs, graphics designers)?

What advantages have you found to presenting EOPs in flowchart format rather than in text?

What disadvantages?

Are some Owners' Group guidelines easier to translate into flowcharts than others? If so, which are the easier and why?

Would you describe the process you follow in developing flowchart EOPs for a particular plant?

- Sources of technical information
- Involvement of plant personnel (plant engineers, operators, trainers)
- Production of the flowcharts
- Validation & verification
- Operator training
- Revisions & updates

Will the plants you have served be able to revise their flowcharts themselves, or will they return to you for redrafting?

How are the decisions typically made about the level of detail to present in the flowcharts?

How do you break the EOP set into a series of flowcharts? That is, how do you decide how much goes on a single flowchart?

How do you organize each flowchart? Do you translate the generic guidelines directly into flowchart format, step-by-step, or have you found it necessary to rearrange in sequence of actions? If so, under what circumstances?

It has been suggested that the most difficult decisions in a flowchart should occur as far along the flowpath as possible. Have you any experience to suggest that this guidance is useful for EOPs?

What guidance have you followed in designing the flowcharts regarding:

- Symbols used (number, type)
- Line types
- Color-coding
- Sentence Construction

- Presentation of conditional/logic statements
- Placekeeping aids
- Acronyms & abbreviations
- Direction of flowpaths
- Referencing & branching
- Crossing of flowpaths
- Location of arrows on flowpaths
- Use of white space
- Location and construction of cautions & notes
- Text in mixed case or all caps
- Types of decision points (binary or functional)
- Entry conditions

If you haven't followed any particular guidance in these areas, how have these decisions been made? Have you handled these issues consistently at the various plants you have served, or have your practices changed with each plant? If you have taken different approaches at different plants, what were the differences and the reasons for them?

Do you typically provide the plants you serve with a writers' guide that describes the conventions you have followed in developing their flowcharts?

What size of flowcharts have you produced?

How are they mounted in the various plants you have served?

How were the flowcharts used in the plants you have served? Did each operator have his/her own copy, did the SRO read the steps aloud, etc.? Were ROs given text procedures to supplement the flowcharts? In cases where one operator may be reading the flowchart and giving oral instructions to other operators who are performing the tasks, do you make any provisions in the design of the flowchart to ensure that these operators understand the information conveyed graphically in the chart?

Have you observed any particular problems for operators in training to use the flowcharts? If so, what are they?

Have you observed any particular problems for operators in using the flowcharts? If so, what are they?

Have you seen any evidence that operators are resistant to changing from text procedures to flowcharts?

What type of guidance do you think will be helpful to the industry for avoiding some of the pitfalls associated with flowchart EOPs? (Specific guidance vs. a set of objectives such as NUREG-0899.)

APPENDIX C

RESULTS OF INTERVIEWS WITH SCIENTISTS

DATE: 16 February 1988

TO: Val Barnes

FROM: John Fawcett-Long

SUBJECT: Scientist Flowchart Evaluations

I conducted one-on-one interviews with the five scientists in the Human Factors and Organizational Effectiveness Research Center at the Battelle Seattle Research Center. Each scientist has had extensive experience in human factors research. One of the scientists has experience with EOPs.

Each interview lasted from 30 minutes to an hour, during which time each scientist evaluated one or two flowcharts. This resulted, then, in each of the four flowcharts being evaluated by either one, two, or three scientists. The scientists preferred to make free-flowing comments and to ask questions rather than follow the structured format that was prepared from the PGP Flowchart Evaluation Checklist. To ensure that all areas on the checklist would be covered, I interspersed questions intermittently during the interviews. Most of the sections on the checklist were covered by the scientists. Each scientist was told that the objective was to evaluate flowcharts from the perspective of a naive observer who had not worked extensively on the flowchart project and was encouraged to comment freely. I chose beforehand which flowchart(s) the scientist was to evaluate.

Each section of this memo describes comments and issues pertaining to different graphic criteria discussed by the scientists during our interviews. These sections are taken from the Flowchart Evaluation Checklist (see Appendix B). I have added an overall impression section and a general comment section.

LOGICAL, LINEAR PROGRESSION

The scientists were instructed to assess the logic, organization, and flow of the flowcharts. Their comments are summarized in this section.

The starting and exit points presented few problems for the scientists. One flowchart did not clearly mark its exit points. All of the starting points seemed fairly clear; however, one flowchart contained an entry point with several conditions that caused some confusion.

The direction of flow was inconsistent in a few points in two of the flowcharts. The designer apparently sacrificed directional flow consistency in order to maintain a visually pleasing graphic presentation.

Frequently the flowcharts had rectangular symbols containing a conditional statement. Operators were required to continuously monitor the status of a condition until it was satisfied before proceeding. One flowchart used this method extensively. There were also several loops in the flowcharts for the same purpose. One scientist labeled these as "wait loops." It was suggested that a graphic monitoring step be used, and that the procedure be presented in the simplest and most concrete steps to avoid having the operator wait for a condition to have a desirable status before proceeding. This suggestion should limit the number of flowlines used.

In one flowchart, flowlines coming from opposite horizontal directions often met at a point. From these points, another flowline continued down vertically. When encountering this confusing intersection, two scientists had to retrace their steps before proceeding.

One flowpath that contained steps to implement a fairly drastic procedure did not lead to an exit. Being technically ignorant of the procedure, I can only conclude that it was assumed but not graphically portrayed that the last step in this flowpath would be the final step.

Another confusing situation occurred repeatedly in one of the flowcharts. A large rectangle in the chart contained a diamond-shaped symbol with a flowline pointing to a another, smaller rectangle. The diamond and the smaller rectangle were not connected to the larger box. A horizontal line separated this arrangement from a conditional statement located in the box underneath. All of the scientists reviewing this found it difficult to understand the relationships between those elements. One scientist described it as a "free-flowing" configuration.

Another unique step that presented confusion was an action statement in a box that was followed by the word "continue." One scientist noted that, because two different flowlines had emanated from the box, it was unclear in which direction the operator should proceed.

LAYOUT

One frequent comment was that flowcharts required operators to perform tasks concurrently. This presented several issues to the scientists. Each scientist (except the one with technical knowledge of the flowcharts) suggested that it is humanly impossible to do more than one task at the same time. Even if the operator can perform several different paths simultaneously, it is usually not made clear which path the operator should start with, which one was second, and so on.

Another issue mentioned by the scientists was that the sequence of steps may be determined by "geometrics" instead of technical necessity. Assume an operator was directed to perform three paths simultaneously with two of those paths leading to other flowcharts and the other continued along the bottom of the flowchart. If the operator reaches the critical point where he is to continue with the rest of the flowchart, but may not be as advanced in the two other paths, the operator may decide to finish the other paths before proceeding. Operators may be trained to continue, but the graphic presentation in the flowchart does not clearly make that known.

Another key issue for the scientists was the lack of emphasis of placekeeping symbols and important decision points. The flowcharts were described as lacking any kind of emphasis for these elements.

The hierarchy of steps, presentation of relationships between units, and supplemental information caused no comment. The density of the flowchart presented no difficulties except in one chart that apparently had been reduced in size.

SYMBOLS

Scientists commented on the unclear meaning of certain symbols, the inconsistent system of symbols, and, in some cases, the need for additional symbols.

Scientists had difficulty understanding the meanings of some of the symbols used in the flowcharts. In two cases it was unclear whether rectangles were actions or not. In another case, dashed lines around a box indicated an override step, yet it was unclear whether this override was a conditional statement or not. One chart used both open and filled directional arrows without explaining the difference between the two. The scientists were not familiar with a few other symbols.

Two of the scientists thought that a consistent system of symbology was needed instead of having to interpret a symbol by its context, by the particular flowchart, or by the particular plant. One scientist said that in not all cases were parallel symbols of equal size, hence they did not receive equal emphasis.

The scientists recommended that additional symbols or explanations be used to direct operators to other flowcharts, to other parts of the plant, or to supplemental information. More symbols were also needed in a box that contained other decision symbols. Often, the relationship between the overall box and the decision symbols within were not clear and could be misunderstood.

LINES

Four issues surfaced regarding flowchart lines: location of arrows coming out of the symbol, placement or lack of arrows, confusion regarding dashed lines, and long, parallel flowlines placed close to each other.

One scientist commented that lines should be placed in the center of a symbol and should drop straight down.

Lack of arrows caused confusion, as did arrows placed near an intersection of flowlines. One comment referred to the lack of an arrow near a symbol, which was distracting and confusing.

One graph had dashed flowlines. This confused every scientist, and one scientist described them as the most salient feature of the flowchart and felt that the dashes, therefore, gave an inappropriate emphasis to the flowlines.

The final issue with lines was that in one case long flowlines were placed alongside each other and thus ran parallel. This caused one scientist to pause and evaluate. Even though he found that he could follow the flowpath, he still hesitated when encountering the parallel lines.

COLOR

Most of the scientists expressed reservations about the usefulness of color. They felt that if color was to be used, it should be used for emphasis. The scientists recommended that override statements, cautions and notes, and transitions to other procedures or printed aids be color coded. Most of the scientists were cautious about the overuse of color. The use of color seemed superfluous to most.

TEXTURE

The diagrams were shaded adequately, but one scientist thought that they could be improved by having areas in graphs labeled as "desirable" or "undesirable."

TONE

No comments were made regarding tone in the flowcharts.

TYPOGRAPHY

The only significant comment here was that in one flowchart a scientist thought that the text was placed too closely together, making it difficult to read. I noticed that several of the scientists had to move close to examine the flowcharts.

DECISION SUPPORT

The predominant issue regarding decision support involved procedures that require the operator to remember previous steps (e.g., flowcharts containing override steps). A few other steps in the flowcharts required the operator to remember the result of an earlier decision even though no indication was given that that information was to be used later on.

The scientists also had problems with instructions to perform concurrent tasks. They thought that this was "impossible" to do and that the flowcharts did not indicate to the operator which task to perform first and when to start the others. Without specific information the operator will typically start from the left side, complete that path, and continue with the next path to its right. Another ambiguity in concurrent flowpaths is that typically an operator will not exit a flowchart with one procedure before working on the other tasks. This may not be the desired sequence of steps.

Scientists also commented on boxes containing logic or condition statements. These could be simplified to a set of decision symbols. Instead they present an ambiguity often using an <u>IF</u> ... <u>THEN</u> statement. The statement implies that, when a condition is satisfied, the operator is to proceed. But the operator is left to monitor the condition if it is not satisfied. This requires time and energy.

Other minor issues were mentioned. One comment pertained to multiple entry conditions. The scientist questioned whether some, any, or all of the conditions need to be satisfied in order to start the procedures.

The scientist who had experience with the operation of nuclear plants noted that, in the particular flowchart he was examining, a step was virtually repeated without asking if the operation had already been conducted.

Another final comment was that a table included in the note section implied, but did not explicitly state, that certain procedures should be conducted given a set of conditions.

CAUTIONS, NOTES, FIGURES, AND TABLES

The use of cautions and notes probably caused more concern than any other aspect of the flowcharts. The issues here revolved around location of reference to a caution, unclear wording and graphics, lack of emphasis for the cautions, distracting vertical headings used in figures and cautions, and graph increments.

One major issue mentioned by several scientists was that it was not clear to them when the figures or cautions were referred to. Either the reference was not emphasized or placed before the affected step, or the caution itself was not clearly marked. It also was not clear how the figures and tables should be used. Often the references were off to the side instead of immediately before the affected step. The scientists thought that the operators' concentration would be broken and that there would be a good possibility that the cautions would not be read. In some instances, the symbol was not close to the flowline where the operator was referred. Also, some figures were not located near the step that they applied, although they were connected to the figure with dashed lines. These dashed lines often did not have directional arrows.

Cautions often lacked sufficient emphasis. Some scientists suggested that cautions be color-coded for emphasis or least clearly separated from each other; that is, graphs, cautions, and notes should be in distinct that are sections separated by heavy vertical lines.

The symbols used in referring to cautions caused some confusion. In one instance, the symbol referring to a caution, a hexagon, was difficult to distinguish from the symbol referring to a note, a circle. One scientist noted that, in another situation, he had seen the symbol used for a caution used as a symbol to tell the reader to go elsewhere.

Two scientists thought that it was distracting and inconvenient for the headings on graphs to be printed vertically; even the title of one flowchart was printed along the vertical. Their concerns were that the operator would have to turn his head and break his concentration.

Another isolated incident occurred when a tolerance range was stated in a caution. Operators were required to remember the range, return to the operation, and then interpret the range. This could have been simpler. Another tolerance range given in the notes was as large as one-half of the major increments of the graph it referred to, leaving much room for error.

Some other comments were made on the increments used in the figures. These increments should be sensible and easy to interpret. If similar figures are used and placed next to each other, it would be convenient for them to have the same size of increments. Sometimes the increments used were not in even numbers (e.g., 100s or 1000s).

The scientists commented that some of the text used in the notes was difficult to understand and too long, and that references out of flowchart should be more specific. A final recommendation was to eliminate unnecessary notes and avoid repeating information.

TEXT

The scientist found several things in the text worthy of comment: poor English; excessive wording; easily misunderstood abbreviations; imprecise, inconsistent nomenclature; and lack of emphasis for key words or key segments of the sentence. The scientists disliked the use of the words irrespective and irregardless. They also thought that the message should be stated as briefly, succinctly, and clearly as possible. Unnecessary descriptive adjectival phrases were often included. Descriptive terms, however, should not be imprecise or too general.

Abbreviations like "resp." and "pt." can be easily interpreted in a different way than intended. One scientist found that a monitoring statement confusingly described a desirable condition's opposite and not the desirable condition. Another scientist thought that one of the flowcharts could have presented its procedures more clearly using more graphic presentations instead of written text.

OTHER COMMENTS

The scientists, especially the engineer, liked my use of a horizontal and vertical grid to reference comments. They thought that it would be useful for operators in the control room. One of the flowcharts did, however, have its own grid design.

OVERALL IMPRESSIONS

The scientists hesitated to make global statements regarding the flowcharts. Here are some of the comments they did offer: "the graphics are pretty good"; "this flowchart is okay and would be helpful to the user"; "this is a good clear diagram"; and "this one is pretty difficult to read" (stated several times regarding one flowchart that probably had been reduced in size).

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This two-volume report describes the activities, findings, and recommendations of a project entitled "Techniques for Presenting Flowchart-Format Emergency Operating Procedures." The project team surveyed the literature pertaining to flowcharts, reviewed existing flowchart emergency operating procedures (EOPs), interviewed consultants who produced flowcharts, and interviewed reactor operator licensing examiners about the use of flowcharts in nuclear power plants.

Volume 1 of this report discusses the use of flowchart-format EOPs in nuclear power plants and presents issues to be addressed in the design and implementation of flowchart EOPs. Volume 2 presents techniques for preparing flowchart EOPs that were derived from the information discussed in Volume 1 and from NUREG-0899, Guidelines for the Preparation of Emergency Operating Procedures (USNRC, 1982).

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