2 Complexity of Proceduralized Tasks

As raised at the end of Sect. 1.3, it is necessary to construct a novel framework that contributes to the development of a good procedure. In order to understand this necessity more clearly, it may be helpful to review why people show a degraded performance when they are following a poor procedure in real-life.

2.1 Performing Proceduralized Tasks

Although there could be other benefits when we use a procedure, many researchers have commonly pointed out that a good procedure guarantees at least three major advantages: (1) reducing workload, (2) reducing the possibility of human error, and (3) standardizing human performance (De Carvalho 2006; Degani and Wiener 1997; Frostenson 1995; Gross 1995; HSE 2005, 2007; Roth et al. 1994). For these reasons, procedures have been widely used for many decades in large and safety-critical process control systems, such as aviation systems, railway systems, chemical/petrochemical plants and NPPs, and so on (Brito 2002; Guesnier and Heßler 1995; HSE 2007; Long 1984, Stassen et al, 1990, Wieringa et al. 1998). This indicates that a technically correct procedure is crucial to secure the safety of any human involved safety-critical system. However, in addition to the technical correctness, we need to carefully consider whether a procedure is actually able to be carried out with any undue workload. Regarding this, let us consider Fig. 2.1, which shows two examples of the allocation of cognitive resources in conducting proceduralized tasks (Wieringa et al. 1998).

In Fig. 2.1, the circle represents the total amount of available cognitive resources that people can devote to performing a proceduralized task. First, people need to devote their cognitive resources to recognizing characters they read (character recognition: CR) as well as to recognize words formed by characters (word recognition: WR). After that, they need to boil down what is to be done by understanding the meaning of a whole description formed by characters and words (comprehension: CMP). In addition, people need to devote cognitive resources to actually performing what they have to do (task performance: TP), such as remembering the location of a controller or recalling how to manipulate it, etc. However, if people have to complete proceduralized tasks in an unstable environment (or stressful circumstance, such as a severe time pressure or rapidly changing circumstance, etc.), they need to use additional cognitive resources to override the adverse effects of it (i.e., ST). A loss of concentration is a good example of the adverse effects of an unstable environment. Therefore, although the appearance of adverse effects may vary from person to person, it is frequently observed that the amount of available cognitive resources for conducting a proceduralized task is not sufficient in an unstable environment.

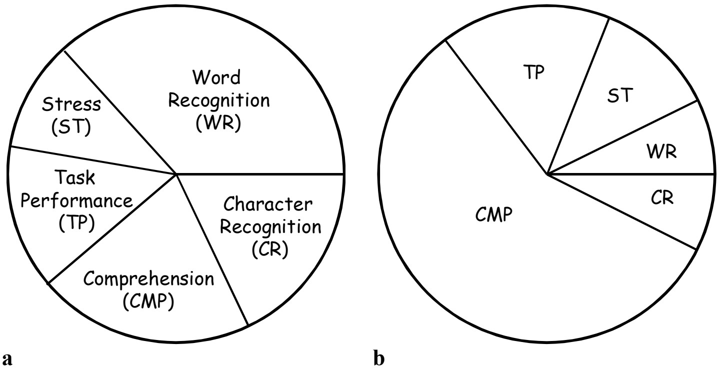

Fig. 2.1 Hypothetical cognitive resource allocations related to carrying out proceduralized tasks (p. 14 of Wieringa et al. 1998)

From this concern, Fig. 2.1a shows an example of the allocation of cognitive resources when people are faced with a proceduralized task containing unfamiliar characters and words. This case may correspond to a mechanic who is trying to calculate the amount of a tax refund using a standard accounting procedure that contains many unfamiliar financial terms. In this case, it is natural to expect that the mechanic is likely to show a degraded performance (e.g., taking a long time to finish the calculation) or make a mistake (e.g., wrong calculation), because he or she will probably not be able to use a sufficient amount of cognitive resources to identify what should be done (CMP) or to carry out what he/she have to do (TP). Moreover, the effect of an unstable environment would be amplified in this case, because there are few cognitive resources to deal with it. Similarly, as shown in Fig. 2.1b, if people have to devote significant cognitive resources to CMP, they are also apt to show a degraded performance or make a mistake. Consequently, in order to avoid the degradation of human performance (or making a mistake), it is very important to develop a procedure that does not challenge the cognitive ability of people.

As a practical remedy, therefore, many procedure writers' guidelines have been developed to enhance the comprehension of proceduralized tasks (i.e., CMP) by manipulating their format, such as sentence structures, font sizes, writing styles, and vocabularies used for the description of the required actions (Brune and Weinstein 1983; EPA 2001; Fuchs et al. 1981; USNRC 1982; Wieringa et al. 1998). For example, let us reconsider two recipes shown in Fig. 1.2 and 1.6 simultaneously. From the point of view of CMP, the second procedural step in Fig. 1.2 has a problem, because it seems to be too unstructured to easily identify what should be done. In contrast, most people will easily identify what they have to do from Fig. 1.6, because a long procedural step is broken down into many distinct and recognizable actions.

It is to be noted that an enhancement of comprehension by reformatting a lengthy proceduralized task is one of the most popular techniques in procedure writers' guidelines. That is, in the beginning, most people believed that all situations could be easily controlled if a set of chronological actions included in a procedure were performed as written in a step-by-step manner. The following statement clearly shows this belief:

> In general, a procedure is a set of rules (an algorithm) which is used to control operator activity in a certain task. Thus, an operating procedure describes how actions on the plant (manipulation of control inputs) should be made if a certain system goal should be accomplished. The sequencing of actions, i.e., their ordering in time, depends on plant structure and properties, nature of the control task considered (goal) and operating constraints (Lind 1982, p. 5).

Accordingly, enhancing the comprehension of a proceduralized task has been regarded for a long time as a fundamental issue in the development of a good procedure. However, Dien (1998) pointed out that a procedure seems to be useful not as a tool for helping people to control a process but as a tool to control people. In other words, it is necessary to realize that people, especially those who are working in a large and safety-critical process control system, have to cope with a rapidly changing situation using a predefined procedure. This implies that performing a procedure is not a simple rule-following task but a problem-solving one that requires high-level cognitive activities as well as skills (Dien 1998; Grosdeva and Montmollin 1994; Kontogiannis 1999a; Roth et al. 1994; Wright and McCarthy 2003). For example, Brito (2002) says the following:

> Pilots' knowledge, expertise and know-how significantly influence the following of written procedures. These cognitive functions enable them to evaluate the situation, to categorize information presented, to evaluate the relevance and the feasibility of information presented, to plan and to execute adequate actions at the proper time (p. 242).

In addition, Spurgin et al. (1988) make the following observation:

> The procedures are very logically structured. The structure of which is related to the key process variable (symptoms) to be observed. Most accidents perturb the plant so as to affect all or a large number of key symptoms. Under these conditions the control-room crew have to simultaneously track several branches of the logic trees. This places a severe burden on the operators. They have to identify the symptoms, evaluate the symptoms that apply and interpret the procedures to carry out the recommended actions (p. 137).

Let us assume a situation in which novices are trying to bake cookies using the recipe shown in Fig. 1.6. Although novices can easily comprehend what they have to do, they may spend additional cognitive resources in the course of performing several ambiguous actions, such as deciding whether the batter is sufficiently smooth or not. That is, since this recipe forces novices to determine the condition of the batter without any specific decision criterion, they may feel a burden to perform the required action in a real situation.

In some respect, this is even a natural phenomenon, because we cannot make an *almighty* procedure describing precise actions in each and every situation. Unfortunately, this problem engenders an adverse effect – *people in a large and safety-critical process control system need to devote cognitive resources not only to identify what they have to do but also to properly conduct it.* For example, in an extreme case, the allocation of cognitive resources could be like Fig. 2.2.

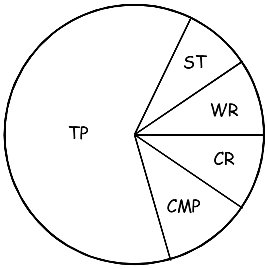

Fig. 2.2 Example of the allocation of cognitive resources when the performance of a proceduralized task is extremely complicated

Obviously, this one-sided allocation is very vulnerable to the degradation of human performance as well as human error, because there are few cognitive resources to conduct the other activities (i.e., CR, WR, CMP and ST). Nevertheless, as mentioned before, it is surprising that most procedure writers' guidelines have mainly focused on the enhancement of a procedure by managing CR, WR and CMP. For this reason, I think that it is critical to develop a systematic framework by which the quality of procedures can be evaluated from the point of view of TP. One promising way to resolve this problem is to measure the complexity of proceduralized tasks, because it is expected that the more the complexity increases, the more the demand of cognitive resources increases.

2.2 Managing the Complexity of Proceduralized Tasks

Related studies have revealed that the amount of effort to be put into a cognitive task (e.g., choice or selection) could be measured as the sum of well-defined units of thought (or elementary information process, EIP), such as *READ*, *RETERIVE*, *MOVE*, *ADD*, etc. (Campbell and Gingrich 1986; Jiang and Klein 2000; Johnson and Payne 1985; Shugan 1980; Sintchenko and Coiera 2002). With this result, if we define an effort as *the total use of cognitive resources required to complete a task* (Russo and Dosher 1983), then it is expected that the amount of effort will be proportional to the complexity of proceduralized tasks. For example, Campbell and Gingrich (1986) articulated that a complicated task places substantial cognitive demands on a task-doer for comprehension (i.e., CMP) and execution (i.e., TP). This strongly indicates that people have to spend more cognitive resources in the course of carrying out a complicated proceduralized task because they need to process more cognitive activities compared to an easy one (Arend et al. 2003; Jonassen 2000). Accordingly, Fig. 2.3 clarifies why we have to manage the complexity of proceduralized tasks.

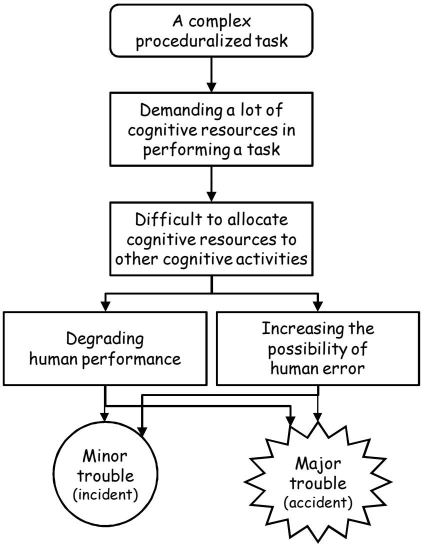

Fig. 2.3 The effect of a complicated proceduralized task on unfavorable consequences

Above all, complicated proceduralized tasks may compel people to spend additional cognitive resources on TP. This results in a decrease in cognitive resources to be spent on other cognitive activities, such as CR, WR or CMP. Because of the lack of cognitive resources, people are likely to either show a degraded performance or make a mistake (Morris and Rouse 1985; Rouse and Rouse 1983; Woods 1990; Woods et al. 1990). In most cases, a degraded performance and human error just cause minor troubles or incidents with a tolerable consequence. However, there are times when an impaired performance as well as human error are unacceptable because they trigger irreversible consequences. For example, a deviation from procedures is one of the typical human errors that culminate in major troubles or accidents in a large and safety-critical process control system (Degani and Wiener 1990, 1997; Lauber 1989; Marsden 1996). Here, it should be noted that a large portion of these deviations is due to the complexity of proceduralized tasks. That is, since people frequently feel an excessive workload due to a complex procedure, they are susceptible to unintended deviations from it. Degani and Wiener (1990) referred to this deviation as *distraction-due-to-workload* (p. 33). A more interesting point is that the complexity of proceduralized tasks seems to contribute to the occurrence of violations (Gross 1995; Hale 1990; Wood 1986).

In general, a violation implies any intended deviation from rules, procedures, or regulations (HSE 1995; Reason et al. 1998). Nevertheless, most violations can be regarded as not malicious actions (e.g., *sabotage*) but a kind of optimized response to satisfactorily perform the required tasks under a given constraint (Gross 1995; Helmreich 2000; HSE 1995; Reason et al. 1998). For example, Dien (1998) stated that "The operators are often called on to respond to situations or events that are not explicitly featured in the procedure. … Some actions required by the procedure may not be totally clear, thereby obliging the operators to take real-time initiatives and decisions in order to overcome any ambiguity (p. 183)." Therefore, as Degani and Wiener (1990) commented, it is meaningful to regard violations as "Deviations from those practices deemed necessary to maintain the safe operations of a hazardous system (p. 42)."

Ironically, operating records have clearly shown that violations are one of the primary sources of major accidents (Perrow 1984; Wiegmann and Shappell 2001). Therefore, from the point of view of securing a sufficient level of safety, it is very important to understand why people violate a procedure. In this regard, several researchers have provided insightful clues. Degani and Wiener (1997) stated that "A procedure that is ponderous and is perceived as increasing workload, and/or interrupting smooth flow of cockpit tasks, will probably be ignored (p. 306)." In addition, Marsden (1996) pointed out that "The operators reported that working with procedures made work much less rewarding and the job more difficult than it would otherwise be (p. 111)." Finally, Macwan and Mosley (1994) have the following to say:

> It is assumed that all plant personnel act in a manner they believe to be in the best interests of the plant. Any intentional deviation from standard operating procedures is made because the employee believes their method of operation to be safer, more economical, or more efficient or because they believe performance as stated in the procedure to be unnecessary (Macwan and Mosley 1994, p. 143).

The above statements emphasize one common tendency as depicted in Fig. 2.4.

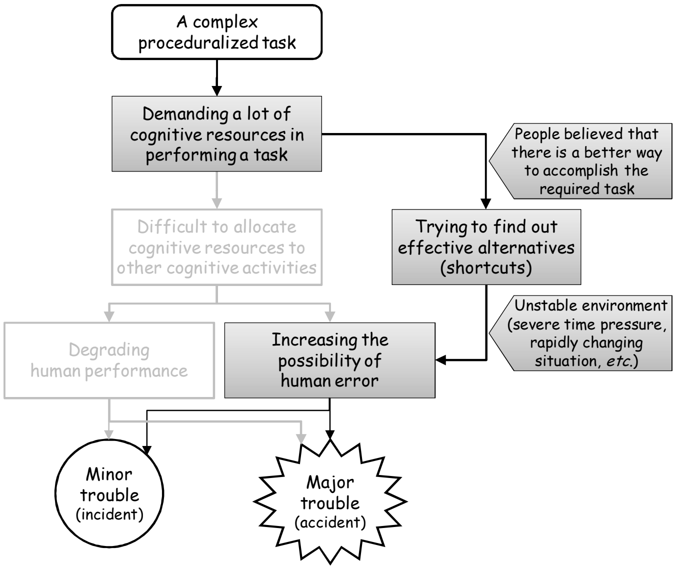

Fig. 2.4 Side effect of a complicated proceduralized task – searching for shortcuts

That is, although there would be many other reasons for violations, people are likely to deviate from a procedure if they believe that there is a better way to accomplish a complicated proceduralized task (i.e., saving cognitive resources by customizing the complicated proceduralized task). It is very fortune that, in most cases, the result of these violations is not harmful but even effective to a certain extent. However, if a less harmful violation is combined with an unstable environment, it is strongly expected that the possibility of human error will drastically increase (Williams 1988; Reason et al. 1998). This means that we have to carefully consider the side effect of a complicated proceduralized task.

Consequently, as illustrated in Fig. 2.5, there is no doubt that we have to actively manage the complexity of proceduralized tasks from the point of view of TP. Otherwise, we would probably face a difficulty in reducing the possibility of major troubles or accidents triggered by complicated proceduralized tasks.

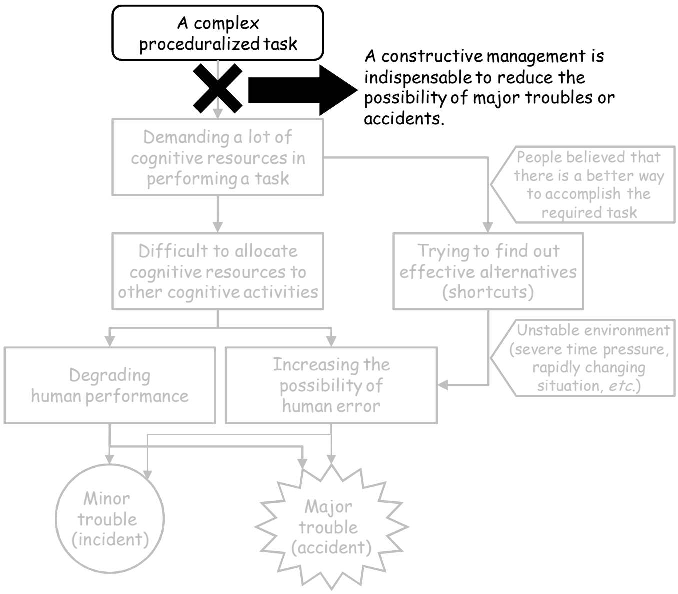

Fig. 2.5 The necessity of managing the complexity of proceduralized tasks

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