1 Introduction

On November 28, 2006 at 4:00 pm, an airplane belonging to one of the small domestic carriers was approaching Jeju International Airport located in the largest island of the Republic of Korea. There were 69 passengers and 4 flight attendants on board. At 4:15 pm, the pilot of the airplane tried to land at the airport. At that time, the pilot recognized that there was a sudden rush of wind. Therefore, instead of a soft landing, where the main landing gear of the airplane touches down first, the pilot decided to attempt a hard landing with its nose landing gear. Unfortunately, in the course of landing, the nose landing gear broke off due to a mechanical failure. However, although the airplane skidded off the runway for a while, there were no serious injuries. As a consequence of this event, the airport was closed for about 3 h. Finally, at 7:45 pm, the airport returned to normal.

The above is the brief reconstruction of an event based on the report of an aircraft accident occurred at Jeju International Airport of the Republic of Korea (ARAIB 2006). It was a stroke of good luck that there were no serious injuries. However, what I want to emphasize from this event is that the airport restored its function within 3 h thanks to the Airplane Accident Emergency Response Manual (Article 2006). This manual was developed by the National Security Council of the Republic of Korea in 2005 to specify detailed responses with clear responsibilities regarding various kinds of emergency events that are likely to occur in an airport. Therefore, according to this manual, necessary counterplans were properly identified and then systematically carried out, such as escorting injured people to hospitals, removing the broken-down airplane from the runway, and cleaning up foreign objects (i.e., debris) from the runway, etc. Without this manual, it is evident that a huge amount of visible as well as invisible loss would have been inevitable. I think this event is a typical example illustrating *why we need a procedure.*

1.1 What Is a Procedure?

Without the loss of generality, we can define a procedure as a set of proceduralized tasks that present step-by-step instructions in the form of procedural steps composed of many actions (Inaba et al. 2004; Wagner et al. 1996). Figure 1.1 de-

picts the canonical structure of a procedure including proceduralized tasks, procedural steps, and the associated actions.

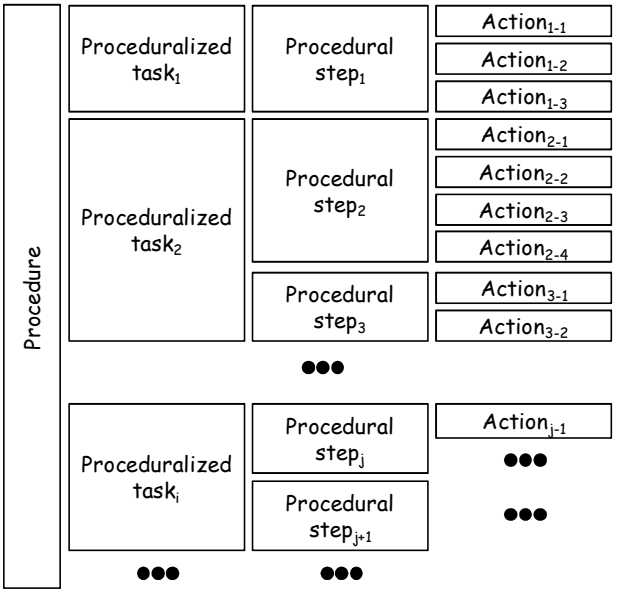

Fig. 1.1 Procedure, proceduralized tasks, procedural steps, and actions

There is no doubt that a procedure containing step-by-step instructions is very useful when people have to accomplish several specific tasks, such as safety-critical tasks, highly complex (or complicated) tasks, rarely performed tasks, and unfamiliar tasks (HSE 2007; Inaba et al. 2004; Wieringa et al. 1998). In addition, it is strongly recommended that a procedure should be developed so that even novices can follow the actions described in it, because (1) both experts and novices have shown a better performance when they used a procedure written for novices and (2) experts can be regarded as novices when they were faced with rarely performed or unfamiliar tasks (Duffy et al. 1983; Inaba et al. 2004; EPA 2001).

For these reasons, many practical principles and guidelines to develop a good procedure have been suggested for several decades. For example, Wagner et al. (1996) emphasized that "a lengthy or complicated procedure may be divided into a series of related subtasks as long as each subtask accomplishes a distinct, recognizable objective (pp. 10-48)."

It is to be noted that the same principle can be applied to proceduralized tasks and procedural steps, such as the subdivision of complicated proceduralized tasks into a series of recognizable procedural steps or the subdivision of complicated procedural steps into a series of recognizable actions (Wieringa et al. 1998). At any rate, this guideline is very important because it is anticipated that people will be able to easily identify *what should be done* or *how to do it* from procedures that consist of a series of distinct and recognizable actions.

However, it seems that a more important problem is to develop a procedure that allows people to easily and correctly carry out the proceduralized tasks in a real situation. In order to understand this issue more clearly, I would like to introduce a private episode related to baking cookies.

1.2 Recipe for a Chocolate Chip Cookie

A couple of years ago, I decided to try simple cooking, because it seemed to be a good idea to share a common memory with my daughters, Eun-su and Eun-sang. At that time, I was sure that I could make it, because not only I have general knowledge about cooking but also I know how to use kitchenware. After carefully comparing many different kinds of cuisine, I chose cookie baking because it seemed to be relatively easy. Naturally, I bought a cookbook containing many practical recipes for beginners. In the course of reviewing the contents of the cookbook, I remembered that my daughters loved chocolate chip cookies. Thus, I chose the recipe for chocolate chip cookies, which consists of (1) a list of ingredients and (2) a proceduralized task that consists of three procedural steps with the associated actions (Fig. 1.2). It is to be noted that the recipe I used was translated into English based on a recipe found on the Internet (Allrecipes 2009).

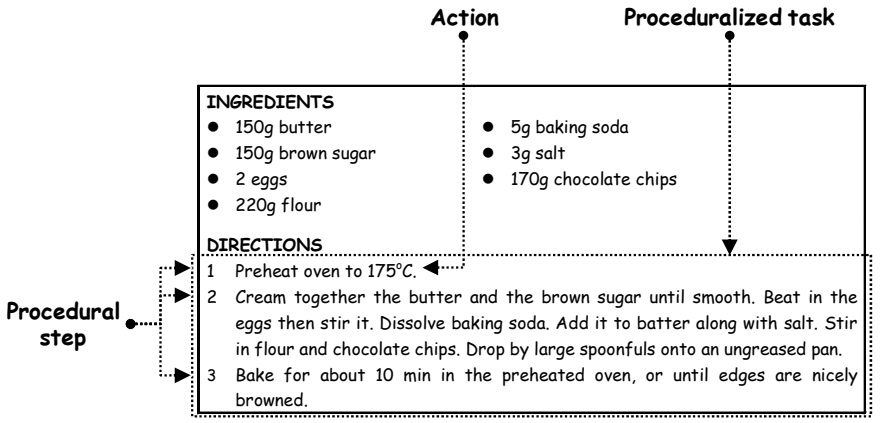

Fig. 1.2 Chocolate chip cookie recipe used by author

With this recipe, I prepared the ingredients and then preheated the oven. I put the butter in a big mixing bowl with the brown sugar and then beat it up all together with a big spoon. About 5 min later, since I thought that the batter seemed to be *sufficiently smooth*, I mixed it up again after adding the eggs, the baking soda, and the salt. Then, I mixed the batter for about 5 min with the flour and chocolate chips.

When the batter was done, I dropped it onto the ungreased pan as *large spoon-*

fuls using the big spoon that I used to mix the batter. Finally, I put the pan in the preheated oven, and waited for 10 min. But the cookies still did not seem to be done after 10 min, because the edges still remained in a *light brown color*. So, I left cookies in the oven for a few more minutes to see *browned edges*. A couple minutes later, I took the cookies out of the oven and let them cool for several hours.

I thought that I had followed the recipe exactly, but my daughters did not like my cookies. My oldest daughter, Eun-su, took a bite and said, "This cookie is too hard and has a bitter taste, dad." Moreover, Eun-sang did not even look at the cookies. It was apparent that, although I baked *edible* cookies, I failed to bake *delicious* cookies with which to impress my daughters. Thus, I explained what I did to my wife in order to find out what was the matter with my cookies. As a result, I realized that I made at least three mistakes in the course of baking the cookies.

First, although I mixed the batter for 5 min, it was not enough time to make a smooth batter with a big spoon. My wife said that I should have stirred the batter for at least 15 min and that 5 min would have been enough for a mixing machine or a hand mixer. Second, I did not sift the flour before adding it to the batter, which is a basic step in baking most cookies. Accordingly, small lumps that might cause the cookies to bake unevenly were created in the batter. Third, since the spoon I used to drop the batter was too big, the cookies came out too big. Consequently, 10 min was not enough to have nicely browned edges. This forced me to wait for several more minutes, and as a result I got hard and bitter tasting cookies. After my wife's explanation, I conceded that baking cookies was harder than it seemed.

It is to be noted that the nature of the second mistake is different from the others, because it stemmed from a lack of basic knowledge about baking cookies. Therefore, once I have gained this knowledge, I do not think I will make the same mistake again. However, it should be emphasized that the other mistakes were caused by the required actions difficult to actually carry out. That is, I felt frustration as well as confusion in performing the required actions described in the recipe, because it was quite tricky to determine such matters: *what makes for a smooth batter*, *how long I should mix the flour*, *how much makes a large spoonful*, *what is meant by nicely browned edge,* and so on. This strongly implies that, unless I acquire sufficient experience in baking cookies, I will probably make similar mistakes again.

1.3 What Is a Good Procedure?

In order to bake cookies, I bought a beginner's cookbook, and carefully followed the sequence of actions prescribed in the recipe. But the result was very disappointing. Fortunately, if we look at the bright side of this episode, this may serve as a nice example for elucidating a banal but always relevant issue – *what is a good procedure?*

In many cases, we are able to deduce the necessary function of a subject from

the provenance of the word indicating it (i.e., etymology). As an example, let us consider the etymology of the word engineer, as depicted in Fig. 1.3 (Etymonline 2008).

Engineer

c.1325, "constructor of military engines," from O. Fr. *engigneor*, from L.L. *ingeniare* (see engine); general sense of "inventor, designer" is recorded from c.1420; civil sense, in ref. to public works, is recorded from 1606. (…)

Fig. 1.3 Etymology of "engineer"

The above etymology indicates that an engineer is an inventor or a designer who can make a machine (e.g., an engine) actually works. From this point of view, one of the necessary functions (or virtues) of an engineer is probably to provide a practical solution, such as a creative design or an outstanding idea. Consequently, we can say that a person who comes up with a practical solution is a good engineer.

In a similar vein, we are able to extract the necessary function of a good procedure from its provenance (Fig. 1.4).

Procedure

1611, "fact or manner of proceeding," from Fr. *procédure* "manner of proceeding" (1197), from O.Fr. *proceder* (see proceed). ...

Fig. 1.4 Etymology of "procedure"

From Fig. 1.4 it is evident that the word *procedure* came from *proceed*, whose the origin is shown in Fig. 1.5.

Proceed

1382, from O.Fr. *proceder* (13c.), from L. *procedere* "go forward, advance," from pro- "forward" + cedere "to go" (see cede). (...)

Fig. 1.5 Etymology of verb "proceed"

If we consider the provenance of these words simultaneously, we immediately see that one of the necessary functions of a procedure is to provide a fact (e.g., information) or manner (e.g., a detailed way of doing or the correct sequence of actions) that is helpful for going forward (i.e., carrying out) to achieve a given goal or purpose. Therefore, ideally, we can say that *a good procedure should provide crucial contents (such as information, detailed action specifications and the sequence of actions, etc.) so that people, even novices, can properly perform the required actions to achieve their goal or purpose in a real-life.*

In light of this concern, the recipe shown in Fig. 1.2 appears to be a poor procedure to some extent, because I made several mistakes in applying the recipe to

baking cookies (i.e., a real-life). This problem can be understood if we compare the following three actions pertaining to one of my mistakes – *making a smooth batter*.

A1	Cream together the butter and the brown sugar *until smooth*.
A2	*Using a hand or stand mixer*, cream butter and sugars *until incorporated and smooth* (Megnut 2007).
A3	*Using a mixer fitted with paddle attachment,* cream butter and sugars together *until very light, about 5 min* (NYT 2008).

It is to be noted that, except for the first action (A1) shown in Fig. 1.2, I found the second (A2) and the third action (A3) by searching the Internet. At any rate, if we focus on the italicized parts of the three actions, we immediately realize that A2 and A3 contain more information than A1. That is, although the length of each action description in A2 and A3 is longer than in A1, A2 provides information about a useful tool to make the batter. In addition, A3 provides the operation time of the suggested tool, by which we can confirm that the batter is ready. For a beginner like me, it is assumed that a recipe containing the required actions written in the form of A3 is a good procedure, because I could have made the smooth batter more easily and correctly. This strongly implies that I could have baked more impressive cookies with a good procedure.

Here, it should be noted that I would have made the same mistakes even if I had used the new recipe shown in Fig. 1.6, which was modified based on a common principle – *the subdivision of a lengthy procedural step into a series of recognizable actions*.

DIRECTIONS

1 Preheat oven to 175°C.

2 Prepare the batter.

- 2.1 Cream together the butter and the brown sugar until smooth.
- 2.2 Beat in the eggs then stir it.
- 2.3 Dissolve baking soda.
- 2.4 Add it to batter along with salt.
- 2.5 Stir in flour and chocolate chips.
- 2.6 Drop by large spoonfuls onto ungreased pans.

3 Bake for about 10 min in the preheated oven, or until edges are nicely browned.

Fig. 1.6 Chocolate chip cookie recipe with modified second procedural step

This means that we need a novel framework that can deal with the indispensable question of how to develop a good procedure – *does a procedure contain essential instructions so that people, including novices, can perform the required actions to achieve their goal or purpose in a real situation?*

1.4 Scope of Book

Simon and Hayes (1976) pointed out that following instructions is one of the most difficult tasks encountered in daily life. Regarding this, Wright (1981) stated that there are three problems making the performance of instructions difficult. The first one is the technical correctness of procedures, because there are times when the information included in procedures is wrong. The second problem is the presentation of procedures, because the language and illustrations used in procedures are not always easily understood. The last problem is the unstructured information, because it may be inappropriately organized for the required tasks. Therefore, Wright asserted that a good procedure needs accurate information, a clear presentation, and structured information.

It should be noted that, in the previous section, we stated that a good procedure should provide essential instructions that are helpful for achieving the required tasks in a real situation. This definition is directly comparable to the last problem – *that of providing structured information*. Unfortunately, it seems that, as will be explained in Chap. 2, most research topics related to procedures seem to focus on the first and second problems issued by Wright. In this book, therefore, I would like to suggest a systematic framework for quantifying of the complexity of proceduralized tasks because it is helpful to resolve the last problem that we are concerning about.

In order to facilitate understanding the features of a quantification framework, it is helpful to provide detailed examples illustrating how to quantify the complexity of proceduralized tasks. To this end, emergency tasks prescribed in the emergency operating procedures (EOPs) of nuclear power plants (NPPs) are considered in this book. The following reasons manifest why the provision of good EOPs is critical to secure the safety of NPPs.

- *Safety-critical system* Traditionally, NPPs have actively developed diverse procedures to provide helpful instructions for most tasks to be conducted by plant personnel; one of the representative examples is EOPs (Dang et al. 1992; Mumaw et al. 1993; Wieringa and Farkas 1991). Here, as recognized from the Three Mile Island (TMI) accident, the successful performance of EOPs is a prerequisite to guarantee the safety of NPPs, because even a trivial human error could result in an irrecoverable consequence (Kemeny 1979; Wilkinson 1984).
- *Highly complicated task* NPPs are one of the most complex process control systems in the world (Perrow 1984). In addition, the operating personnel of NPPs should conduct emergency tasks prescribed in EOPs under very stressful circumstances (Kontogiannis 1996; Meister 1995). This strongly indicates that some emergency tasks could jeopardize the cognitive ability of operating personnel.

- *Rarely performed or unfamiliar task* Although the design of NPPs is very complicated, operating history has shown that the frequency of the occurrence of major accidents is very low (Amalberti 2001). However, this is a general tendency for other safety-critical systems, because considerable effort has been devoted to securing a sufficient level of safety. For example, Greenberg et al. (2005) reported that the frequency of the occurrence of major accidents in the aviation industry is 0.7×10^{-6}/h. This means that, on average, a captain should come across a major accident when he or she has flown over million hours. Accordingly, it is very natural to regard emergency tasks as rarely performed or even unfamiliar tasks.

This book consists of three parts. Part I provides some fundamental concepts that play a crucial role in quantifying the complexity of proceduralized tasks. Part II is the core of book. The six chapters included in this part will allow the reader to understand how to quantify the complexity of proceduralized tasks and to see the validity of the quantification framework. To this end, detailed explanations will be given based on the emergency tasks prescribed in the EOPs of NPPs. Then, several promising applications pertaining to the quantification framework will be reviewed in the first chapter of Part III. Finally, concluding remarks will be made in the last chapter after discussing several insights pertaining to the quantification framework.

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