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Recommendations for Reducing Ambiguity in Written Procedures

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Abstract

Previous studies in the nuclear weapons complex have shown that ambiguous work instructions (WIs) and operating procedures (OPs) can lead to human error, which is a major cause for concern. This report outlines some of the sources of ambiguity in written English and describes three recommendations for reducing ambiguity in WIs and OPs. The recommendations are based on commonly used research techniques in the fields of linguistics and cognitive psychology. The first recommendation is to gather empirical data that can be used to improve the recommended word lists that are provided to technical writers. The second recommendation is to have a review in which new WIs and OPs and checked for ambiguities and clarity. The third recommendation is to use self-paced reading time studies to identify any remaining ambiguities before the new WIs and OPs are put into use. If these three steps are followed for new WIs and OPs, the likelihood of human errors related to ambiguity could be greatly reduced.

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1. INTRODUCTION

Human error is a major concern across the nuclear weapons (NW) complex. Prior reports by Sandia and DOE on the Pantex Plant have indicated that failures to follow operating procedures can lead to potentially hazardous situations (Witmer, 2001) and are the leading cause of reportable occurrences (Brannon, Wenner, Ramos, & Stevens, 2004). The procedural errors that were observed in these studies were caused by a variety of factors, including ambiguous or easily misinterpreted procedures, conflicting procedures, reliance on "operator techniques" instead of formal procedures, and personal biases on the part of the author of the procedure. DOE Order 5480.19 on the conduct of operations requirements for DOE facilities states that "procedures should be written in such a way that they can easily be used without making mistakes." Further, it states that "procedure preparation, verification, and validation should receive high-level attention… Review, verification, and validation should be formalized for written and software procedures." The findings of the Sandia and DOE reports indicate that more work is required to meet these standards. Improvement of the processes for writing, validating, and using operating procedures (OPs) and work instructions (WIs) could lead to a reduction in the number of occurrences at DOE facilities.

To assist with meeting these standards, a review of relevant literature on language comprehension, ambiguity, and procedure writing guidelines in other fields was conducted. This report outlines guidelines based on that review that could be implemented to improve procedure writing, review, and validation.

1.1. Ambiguity in English

The English language contains many sources of ambiguity at all levels, from the level of words to the level of texts. Ambiguity at the word level may be the most problematic, because English words with different meanings can share the same spelling. These words are called homonyms. For example, the word "bank" is a homonym that can refer to the bank of a river or to a financial institution. The meanings of homonyms are often, but not always, disambiguated by their context. For example, in the sentence "I'm going to the bank," the word's meaning is still ambiguous. Some words can be used as multiple parts of speech, such as the words "control" and "bear," both of which can be a noun or a verb. The meaning of the noun and verb uses of a word may or may not be related to one another, increasing the likelihood of ambiguity.

Verbs have even more potential for ambiguity than nouns. In addition to having multiple meanings, verbs can have multiple senses. Many verbs have a range of related meanings, often extending from concrete actions to metaphorical expressions. Each of those variants is referred to as a verb sense (Hare, McRae, & Elman, 2004). The meanings of the senses of a verb are related by definition (if they were unrelated, they would be considered homonyms), but the relationships between them can be very distant. In addition, verbs can be used in a variety of grammatical structures. Each verb typically occurs on one structure more often than any other, a pattern that language researchers refer to as "verb bias" (Garnsey, Pearlmutter, Meyers & Lotocky, 1997). The two most common types of verb bias (in English) are direct object bias and subordinate clause bias. Verbs with a direct object bias most commonly (and sometimes obligatorily) occur in sentence structures where they take a direct object as an argument. For example, the verb "buy" has a strong direct object bias and is almost always followed by a direct object, the item that is being purchased. The verb "argue" has a strong subordinate clause bias and rarely takes a

direct object. The problem of ambiguity introduced by verb bias is confounded by the fact that different senses of the same verb can have different preferred structures. The verb "claim" has a strong subordinate clause bias when it is used in the sense of making an argument, but it has a strong direct object bias when it is used in the sense of claiming a prize. Previous research has shown that these issues can be very problematic for sentence comprehension. When verbs are used in structures other than their preferred structure, readers often misinterpret the meaning of the sentence (Christianson et al., 2001). Even when they are alerted to their mistake, many readers are still very confident in their original interpretation of an ambiguous sentence and disregard the conflicting evidence.

English speakers manage to navigate the ambiguities of their language successfully most of the time. However, the consequences of an ambiguity that leads to misunderstanding can be very high, especially within the NW complex. Attention should be given to reducing ambiguity as much as possible in written procedures and work instructions. Research in the domain of cognitive psychology, particularly in the areas of language comprehension and sentence processing, can be used to construct guidelines for minimizing ambiguity. Section 2 outlines a set of recommendations based on the research in those fields.

2. RECOMMENDATIONS FOR MINIMIZING AMBIGUITY

Recommendation 1a: Use cognitive psychology techniques to improve the recommended word lists provided by DOE and Pantex for technical writers.

Recommendation 1b: Create a software tool for technical writers that can identify potentially ambiguous words.

Industries such as the aerospace industry commonly use restricted languages such as Simplified English (AECMA, 1995) for writing procedures. Simplified English (SE) is a standardized subset of English words that are limited to only one sense. Empirical research has demonstrated that the use of SE can improve comprehension and reduce errors, particularly for complex texts (Chervak, Drury, & Ouellette, 1996; Shubert et al., 1995). However, using SE places a very high burden on writers and there is little research indicating which aspects of the language are most useful and effective.

The current writer's manuals for DOE and Pantex suggest that writers make instructions as clear and simple as possible. They also provide lists of action verbs that are recommended for use in written procedures. However, the two lists contain different sets words and sometimes different definitions for the same word. In addition, recent research (Matzen, 2009) indicates that many of the verbs in the two lists have the potential to be ambiguous.

In order to limit the potential for ambiguity without placing overly burdensome restrictions on writers, we suggest compiling a dictionary of commonly used terms that would be the standard for NW work. The words in the dictionary should be defined based on how they are most frequently interpreted by the target audience for the OPs or WIs. It should also include alternate senses of each word so that writers can check for other interpretations that could make the instructions ambiguous.

The first step in compiling a dictionary would be to conduct a corpus study to determine what words are most commonly used in OPs and WIs that are written for NW work. The most common context for each word, its less common uses, and the frequency of each should be

recorded. Then, a norming study similar to the one described in Matzen (2009), but with a larger sample size, should be used to elicit word interpretations from technicians who use WIs. The dictionary definitions for each word should be based on the most frequent responses from people in the target audience. The word meaning that is produced most frequently by the respondents is the one that is most likely to come to mind first when they are reading and using WIs. By defining the word according to its most frequent use and avoiding other uses of the word whenever possible, writers can minimize the potential for ambiguity in their WIs.

In order to reduce the burden on writers and allow them to convey information as effectively as possible, they should not be limited to using the words in the proposed dictionary or to always using them in only one way. However, they should be aware of other interpretations of the words that could lead to confusion and ensure that the context in which the potentially problematic words are used makes their meaning completely clear. To help writers to identify potential sources of ambiguity, the usage frequency information collected from the corpus study and the norming study could be used to develop a software tool that identifies words that have multiple common meanings. Similar tools exist for Simplified English to help writers check their compliance with the rules of that language. In this case, the tool could be used to highlight words with multiple meanings so that writers can look at the other meaning and determine if any of them would be plausible in a particular context. If so, the writer could revise the WI to eliminate any other interpretations.

Recommendation 2: After new WIs have been written, one or more people who were not involved in writing the WIs should perform a second check for ambiguities and for clarity.

Prior work by Sandia (Brannon et al., 2004) found that one source of error was differences in how writers and their intended audience interpreted WIs. To minimize this, all WIs should be reviewed by at least one person other than the writer, and preferably by more than one person. Ideally, the reviewers would be from the WI's target audience – the operators who will be using these or similar WIs. While the DOE Writer's Guide recommends consulting with operators during the development of procedures, their input should also be included as part of a formal process for reviewing new procedures. This review should focus on finding any portion of the text that could have more than one interpretation so that those sections can be clarified.

There may be cases in which the writers and the readers both think that there is only one interpretation a particular instruction, and yet they may differ on what that interpretation is. Using a dictionary based on the readers interpretations (as described above) should help to reduce the likelihood of such a situation. However, to further reduce the probability, it may be beneficial to have the reviewers write down their interpretation of the instructions using different words. Then the original writer can evaluate how well these interpretations correspond to the intent of the instructions.

Recommendation 3: Use self-paced reading time studies as a final check for ambiguities.

Reading time studies are a commonly used tool in language processing research (c.f. Just, Carpenter & Wolley, 1982). In these studies, participants read sentences that are presented one word at a time (mimicking the eye movements that would normally reveal new information as a

person reads a text). The participants control the duration of each word's presentation by pressing a button to reveal each new word. Readers slow down significantly when the sentence is confusing or when the newly revealed words do not fit with the reader's predictions about how the sentence will proceed (Boland, 1997; Garnsey et al., 1997; Traxler, Prickering, & McElree, 2002; Trueswell, 1996). Conducting a reading time study with a small group of participants from the target audience would be a highly effective way to identify any remaining ambiguities or misleading aspects of new WIs and OPs. It may be desirable to develop software to present new WIs in a self-paced reading time study format and to automatically identify any sentences that deviate statistically from an individual's typical pattern of reading times. However, even without automated software, this sort of study could be conducted and analyzed quite quickly.

It should be noted that reading time studies may not be able to identify sentences that are easy to process but are misinterpreted by the reader. Reading time studies are very sensitive to ambiguity, even on the level of temporary ambiguities caused by a normal clause boundary in a sentence (Garnsey et al., 1997) or by misinterpretations of which readers are unaware (Christianson, 2001). However, there may be rare cases where a reader is completely confident in his or her incorrect interpretation of a sentence, and that sentence does not show an unusual reading time profile. Because of this, reading time studies should be performed as a final step in the process of reviewing new WIs and OPs. Prior reviews, such as those discussed in Recommendation 2, should be completed first in order to eliminate sentences that could have multiple interpretations.

3. SUMMARY

The recommendations outlined above should help to reduce every type of linguistic ambiguity in work instructions and operating procedures, and in turn they should reduce the frequency of human errors related to ambiguity, misinterpretation, and author bias. For procedures that are unusual or especially complex, it may be useful to conduct additional tests, such as run-throughs in which operators use the procedures in a mock setting. However, using only the steps outlined here could mitigate many of the sources of human error that have been observed in the NW complex (Brannon et al., 2004; Witmer, 2001). Adopting these recommendations would help procedure writers to meet the standards laid out in DOE Order 5480.19.

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