Designing an on-line multimedia maintenance manual for a production environment

W.P. Brinkman, V.P. Buil, R. Cullen[1], R. Gobits[2] and F.L. van Nes
e-mail: w.p.brinkman@tue.nl

Abstract

Maintenance in production environments is becoming increasingly more complex, as machines become more technologically advanced and need less maintenance. As a result, maintenance personnel face more difficult tasks but at the same time obtain less experience with them. In this context, on-line multimedia manuals were thought to give better support than paper manuals. Three prototypes were designed and tested in an industrial environment, to find out how to design an on-line manual that indeed is better than a paper manual. The evaluation of the first prototype showed that maintenance engineers encountered serious problems with the first prototype of an on-line multimedia manual, as they omitted crucial steps in the task. The literature states that this is a typical problem in the execution of maintenance procedures. Based on findings in the literature, several design guidelines were formulated and applied to a second prototype to reduce the omission of steps in the procedures. This prototype was also evaluated by users. The third prototype addressed another problem encountered in the second evaluation. The people using the prototype experienced problems with switching between the on-line manual and the machine controls. The users made mode errors. To solve this, a third prototype was designed and tested. The results indicate that combining the on-line manual and the machine control into one user interface may prevent mode errors.

Introduction

Nowadays the term ‘proactive maintenance’ is quite popular (Pintelon, Gelders & Van Puyvelde, 1997). It is a combination of design-out maintenance (DOM) and preventive maintenance. The focus of DOM is to improve the design to make maintenance easier or even eliminate it. Ergonomic and technical reliability aspects are important here. As a result of these technical improvements machine parts last longer and maintenance engineers less often have to replace them. This makes the maintenance engineers casual users: people who are using a system at irregular intervals rather than having the fairly frequent use assumed for expert users (Nielsen, 1993).

Unlike a novice user, who would probably read a manual from the beginning till the end, the casual user has some task knowledge and will probably search a manual to find information about things that he has forgotten only. The expectation was that an on-line manual could give better support for searching than a paper manual. Besides

1. Information Technology group (IT), Department Mechatronics, Philips Centre for Manufacturing Technology, Eindhoven, The Netherlands.

2. Psychology and Language in Technology group (PETIT), Faculty of Technology Management, Eindhoven University of Technology, Eindhoven, The Netherlands.

that, it was thought that multimedia techniques - like animation or video - would better express the complex spatial and dynamic operations on hardware. Finally, maintenance engineers may have limited knowledge of the foreign language an on-line manual may be written in, in which case animations and videos might give better support than still pictures.

A prototype of an on-line multimedia maintenance manual was designed to support the maintenance of an inline inspection machine that was situated on the production floor of a factory. The on-line manual described the replacement of one part of the machine, i.e., a camera. The section below looks at the design and evaluation of this prototype. This is followed by an observed problem with the omission of steps. Next, a third prototype is looked at, which was designed to study another observed problem subjects had with applying instructions for machine control. Then, the general result is discussed. The conclusion that can be drawn from this study is given in the final section.

Prototype 1: The first design

The user interface of the first prototype of the on-line multimedia maintenance manual consists of three levels. The first level gives an overview of the machine with the maintenance tasks for which support is available. Selecting a task brings you to the second level, in which an overview of the particular task is given. This overview is presented in the form of several numbered 'cards' laid down side by side, representing the subtasks within the selected task. Each card contains the steps to be performed in that subtask. Clicking on one of the cards, or on one of the steps in a card, brings you to level three of the user interface. In this level the so-called 'information pages' are presented. The cards from level two are packed together - like a card game - on the right-hand side of the screen; on the left the information of the chosen (step in the) subtask is given in the form of a picture or video and some instructions. Figure 1 gives an overview of the complete user interface.

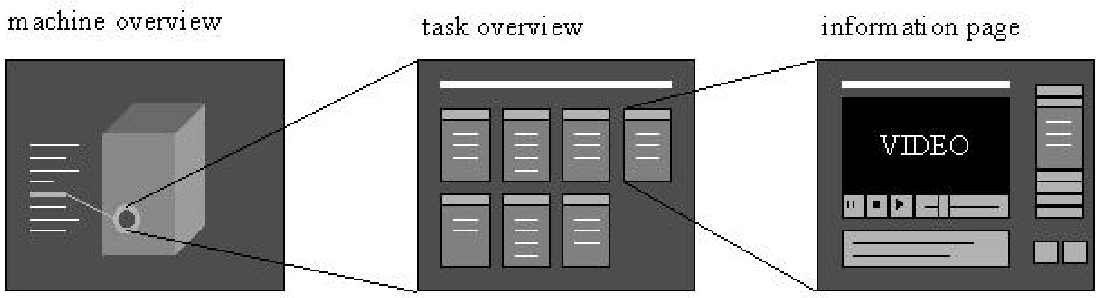

Figure 1: User interface of the first prototype.

We assumed casual users would typically use the on-line manual as a reference guide - searching the on-line manual to find information only about things they had forgotten, as opposed to using the on-line manual as an instruction - reading step by step from beginning to end (Westendorp, 1988). We were interested if this would be so for our situation, because this might be a reason to design some extra support into the prototype. We wanted to find out whether users could finish the task with the prototype using it in either way, and see where the instructions and the video movies were clear enough.

Six maintenance engineers (see Table 1) volunteered to participate in a usability test. In this test the subjects were observed performing the camera replacement task in a real production environment, and interviewed afterwards to collect their opinions on usability and usefulness of the concept in general. In the task the subjects had to operate three systems: the prototype of the on-line manual, the machine control software, and the machine itself. The subjects were wearing a headset with a microphone to collect data through a thinking-aloud protocol. Furthermore, all actions performed by the subjects were registered with two video cameras.

Results showed that the subjects did tend to use the on-line manual as a reference guide. They often started with the task without using the on-line manual, even though the task was totally new to them. This led to problems when subjects skipped necessary steps in the task sequence. These omissions also occurred with people that used the on-line manual more or less as an instruction. The problem of omissions was studied in further detail with the design of a second prototype, as described in the next section.

Prototype 2: Design against omissions

Omitting steps in the execution of a task sequence is a typical problem in the field of maintenance in general. Reason (1990) gives various examples of such omissions in his book, like forgetting to replace a protection cap or to close a valve. These unintentionally omitted steps in maintenance tasks can have severe consequences, as in the Three Miles Island and the Challenger accidents.

There are many information processes involved in the mind of someone applying task instructions to a certain domain, and in all of these processes something can go wrong. One has to *read* the instructions, *understand* them, *remember* them and *apply* them correctly (Wright, 1983). All these processes are prone to errors, especially omissions (Reason, 1990). To reduce omissions in procedures, it is necessary to design an on-line maintenance manual in such a way that (1) omissions are likely to be avoided, (2) those omissions that do occur are detected as soon as possible, and (3) help is given to identify and recover from these omissions.

To help users avoid omissions, one must provide the right conditions to read, understand, remember, and apply the instructions. Therefore, the instructions should preferably be short and clear, in a numbered format with maximally 5 steps per instruction (which helps to remember the actions and keep track of the task when one is switching between the on-line manual and the system maintained) (Reason, 1990). The extent to which people can memorize information depends on the meaningfulness of that information, which can be improved by presenting schemes, metaphors, comparisons, or examples to build accurate mental models (Norman, 1983). To help users to detect omissions as soon as possible, one should constantly give users information on the expected outcome of some steps, so that they can check whether they are still on the right track (Sellen, 1994). In fact, this kind of feedback was already advised by Carroll (1985), in his guidelines for the 'Minimal Manual'. These guidelines also mention recovery information to help identify and recover from likely errors.

Unfortunately, all precautions described above may not help enough if the maintenance engineer does not read the on-line manual. To help solve this, one can use the navigation behaviour of the user in the on-line manual to make assumptions regarding whether critical steps are executed or not. If these assumptions lead to the conclusion that a critical step was not executed, one can issue a warning at the moment a user enters another step that depends on this critical step.

All design guidelines described above have been applied to a second prototype (see Figure 2). Every information page in the second prototype contained step-wise structured instructions, information on the expected outcome after applying these instructions, and information on likely errors and how to recover from them. The user can also mark a step as 'done' to indicate that he has executed the step. This makes it possible for the on-line manual to warn the user if he enters a step that has a preceding step on which it depends and which has not yet been executed.

With this prototype a second usability test was performed to find out the effect of the implemented changes. The eight remaining maintenance engineers (see Table 1) of the maintenance department, who had not volunteered to participate in the first usability test, were now assigned to this test. The test took place in the same setting as in the first test. Table 1 shows that all subjects together only made six omissions in total. This seems to be an improvement, compared to eight omissions the six subjects made in the first test. Studying the subjects' behaviour showed that the extra support given did help them to avoid, detect, identify, and resolve omissions.

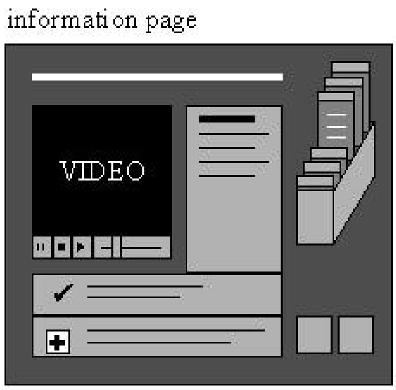

Figure 2: User interface of the second prototype

Prototype 3: Design against mode errors

Besides omissions, another problem was observed: subjects had problems with applying the instructions for the machine control. Four subjects in the second test wanted to do something with the machine itself, while they had to operate the machine control. The concept of two personal computers next to each other also seemed to be somewhat confusing. One subject even tried several times to change a parameter value he saw in a picture of the on-line manual into the one he saw on the machine control display, instead of the other way around. He only understood it in the right way after some help. These problems can be categorized as mode errors, i.e., false classification of a situation. The resulting action may be appropriate for the situation in the user's mind, but inappropriate for the actual situation (Norman, 1981). This problem can have two causes: either (1) the person is not aware that he has to make a classification or (2) the user falsely classifies a situation because the situations involved cannot easily be distinguished. Norman (1981) gives two corresponding solutions: (1) reduce the number of modes and (2) give the person better support to classify the situations. Combining the on-line manual and the machine control into one user interface reduces the number of modes, because instead of using pictures of the machine controls in the on-line manual it is possible to point to the actual controls (Knabe, 1995).

To study what a combined user interface should look like, two concepts were designed: (1) the advisor and (2) the wizard concept. Both had the same layered structure as the previous design, however, in the advisor concept (see Figure 3) the on-line manual and the machine control as a whole are simultaneously visible side by side on the screen. Also in this concept, whenever an instruction in the on-line manual mentions a machine control, a green square surrounding this control starts flashing, which should help the user to focus his attention on the right control. The flashing stops when the user starts operating the machine control. If the machine control stops flashing, the next machine control mentioned in the step automatically starts blinking, and so on. In the wizard concept (see Figure 3), however, the machine controls are not simultaneously visible, but sequentially. The machine controls are assimilated into the instruction text of the information page at those places where they are mentioned. This concept replaces a multi-purpose machine control with a task-specific user interface, which presents a specific machine control at those steps of the task that instruct the user to operate the control.

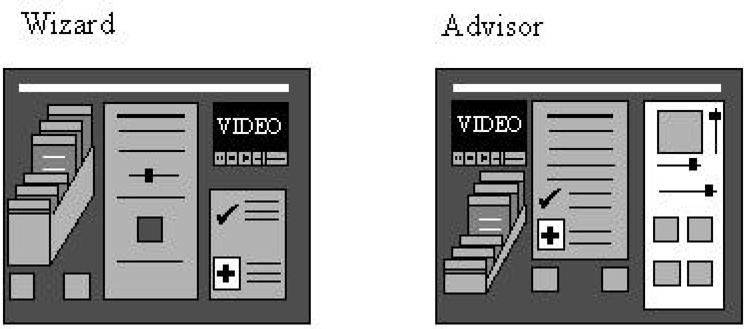

Figure 3: User interfaces of wizard and advisor mock-up.

A mock-up in Visual Basic of each concept was made and afterwards evaluated by performing a cognitive walkthrough. This usability method is a formalized way of imagining people's thoughts and actions when they use a user interface for the first time (Lewis, Polson, Wharton & Rieman, 1990). Eleven software engineers of several engineering departments were assigned to this walkthrough. The participants were asked to individually step through the task using one of the two mock-ups. An important question of the walkthrough was whether people understood that they could operate the machine, during their first contact, by pressing buttons in a manual. A clear indication towards an answer is the way the participants reacted when, after two steps in which they had to perform physical actions on the machine, they were instructed for the first time to use the machine control. Of the six participants who had to do this step with the advisor mock-up, one did not succeed. However, with the wizard mock-up three of the five participants who performed this step for the first time needed help to accomplish this step.

To overcome this problem a new concept was designed. The advisor concept was taken as the starting-point, because it seems to be closer to the prior mental model, in which the machine control and the on-line manual are independent objects. Therefore, the advisor concept was considered more usable and easier to perceive as an interface with which one can operate a machine. In addition, the idea of the wizard concept was adopted, to display the machine control only when needed. However, this time all machine controls were displayed if the instructions mentioned any machine control (Figure 4C). In steps that only consisted of physical actions, the space otherwise occupied by the machine control was used for displaying animations and photos of the physical actions (Figure 4B). We hoped to create a more recognizable user-machine interface that makes a clear distinction between physical actions on the machine itself and operations done with the machine control. Another difference in this concept is the implementation of the card index. To glance through the maintenance task the user has to switch between the instruction text and the card index (Figure 4A). This leaves more screen space for animations, photos, and the machine control.

The surrounding of a machine control that a user should operate flashes in the advisor concept. The participants of the walkthrough reported two problems concerning the flashing. These problems are as follows:

1. Not all people like flashing controls.
2. The moment a control starts and stops flashing is confusing.

To overcome the first problem, the new concept marks a control by drawing a circle around it as is done in Apple Guide (Knabe, 1995). Next, the user himself indicates what instruction he is working on by clicking on the instruction. Based on this indication, a circle is drawn around the appropriate control.

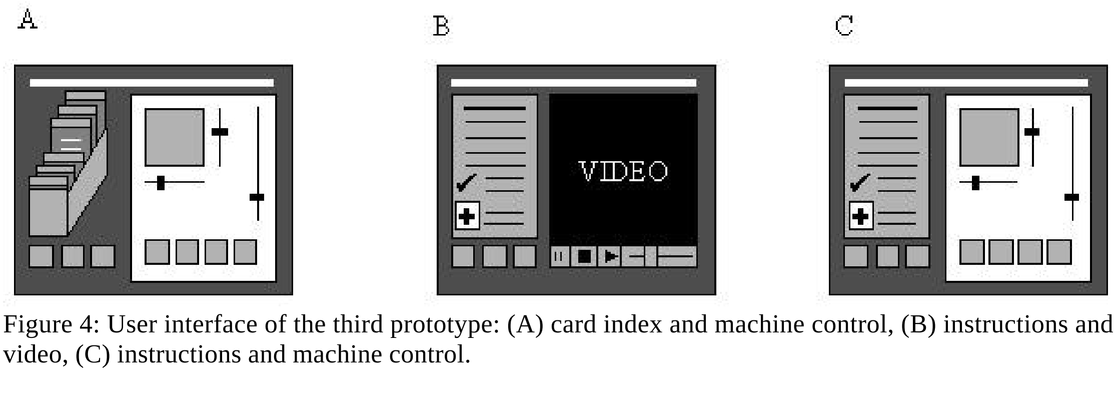

Figure 4: User interface of the third prototype: (A) card index and machine control, (B) instructions and video, (C) instructions and machine control.

A third prototype was built with this new concept. Unlike the two previous mock-ups used in the walkthrough, this time it was possible to actually control the machine with the prototype. The set-up of the test was the same as in the other usability tests, only this time it took place in the design office instead of on the production floor. Eight electronic engineers of an assembly department were assigned to participate, because all maintenance engineers of the maintenance department had participated in one of the previous two usability tests. During the test, only one subject briefly mistook the machine control for a picture. In all other cases the machine control was perceived as a means by which the machine could be operated. There were no cases where subjects mistook an element of the manual interface for a machine control. However, two subjects tried to perform an action directly with the machine itself, whereas it had to be done by the machine control. Therefore, it may be concluded that the distinction between manual and machine control seems more clear and may prevent mode errors, but the distinction between physical actions on the machine and action done with machine controls is not clear.

Subjects rarely used (two times on average) the clickable instructions, even in situations where they would benefit from them. However, there was a clear case where a subject who was searching for a machine control found it immediately after the pencil animation had drawn a circle around it. This indicates that clickable instructions are probably not so usable, but marking a control by drawing a circle around it is a usable way to draw the user’s attention to it. None of the subjects made a negative remark about the fact that the machine control is not always visible. This may indicate that it is not always necessary to display the machine control. When a step describes a physical action, the space occupied by the machine control can then be used for photos or animations.

An expectation raised in the beginning of the study was that multimedia could better support the comprehension of the on-line manual when written in a foreign language. After performing the replacement task, the eight Dutch subjects were given four screen dumps of the English information pages (with videos and pictures) and asked to explain the instructions in their own words. Four independent observers individually judged that only an average of 60 +/- 9% of the instructions was completely understood. Apparently, simply adding animations and pictures does not remove all vagueness of a manual written in a foreign language.

Discussion

Table 1 summarizes the results of the study. Comparison between the results of the usability tests should be done with reservations. First, the subjects that participated in the three usability tests were selected in different ways. In the first test the subjects volunteered, while in the other tests the subjects were assigned to the test by their supervisors. This selection process may have influenced the results. Another issue is the difference in profession of the subjects. Due to practical reasons, we used electronic engineers instead of maintenance engineers in the third usability test. Yet annother problem is the ecological validity. The tests of the first two prototypes were done on the factory floor, whereas the third prototype was tested in a design office. The factory normally is very noisy, while the room of the technical designers is only filled with the noise of people talking and telephoning.

Table 1: Results of usability tests and walkthrough.

Method	Prototype	Average age	Profession	Environment	Sample size	Omissions	Mode error
Usability test	1	38	3 M.M.E.[a] and 3 E.M.E.[b]	production floor	6	8	-
	2	39	3 M.M.E[a]. and 5 E.M.E. [b]	production floor	8	6	4
	3	40	E.E.[c]	design office	8	12	2
Walkthrough	wizard	-	S.E.[d]	design office	5	-	3
	advisor	-	S.E.[d]	design office	6	-	1

[a] mechanical maintenance engineer. [b] electrical maintenance engineer. [c] electronic engineer. [d] software engineer

The most interesting issue, however, is the interpretation of the effect the prototypes have on the dependent variables. The number of omissions per subject observed in the test of the first prototype (1.33) exceeds the number observed in the test of the second prototype (0.75). This suggests an improvement, but the difference is not significant. However, note in this context that more errors in the first usability test may have been omissions but were not classified as such. Subjects in this test pursued inaccurate actions longer after they had made an error. The lack of detection information in the first prototype presumably caused this and led to an accumulation of errors, which made it difficult to classify them. However, the average number of omissions per subject observed in the test of the third prototype is 1.5, which seems *more* than with the first prototype. This may indicate that the user again becomes vulnerable to making omissions in this implementation of an integrated user interface. Finally, the table shows the number of subjects that made a mode error. With the second prototype 50% of the subjects made a mode error, whereas with the third prototype only 20% of the subjects did. Again, although the trend points to a reduction, no significant difference was found.

Conclusion

This study started with the expectation that maintenance engineers, being casual users, would use a maintenance manual as a reference guide. The results of the first test confirm this idea. A second expectation was that an on-line manual could give better search support than a paper manual. The evaluation of the second prototype confirms this to the extent that an on-line manual can give advice at the moment that problems are likely to arise, thus avoiding the need to search for information to solve problems. This could also explain the change in behaviour of the subjects in the final test, in which seven of the eight subjects used the on-line manual from the start till the end. The third expectation was an improvement in comprehension by using multimedia. The results show that multimedia will not lead to a complete understanding of the instructions written in a foreign language.

Summarizing the results of the findings on these expectations, we think that an on-line multimedia maintenance manual might give better support to the maintenance engineer than a paper manual. An on-line manual might reduce omissions, although no significant difference was found. The study also shows that the user may become confused when he has to work with separate systems. The trend of the results points to a reduction of mode errors when a user interface shows the manual and machine control at the same time, thereby making pictures with examples of the machine control in the on-line manual unnecessary. However, no significant reduction was found.

Acknowledgements

This study was conducted as two successive graduation projects at Philips Centre for Manufacturing Technology. We would also like to thank D.G. Bouwhuis and G.W.M. Rauterberg for their comments and advice during the writing of this paper.

References

Carroll, J.M. (1985). Minimalist design for active users. In: B. Shackel (Ed.): *Proceedings of the IFIP Conference on Human-Computer Interaction, INTERACT-84, London, UK, September 4-7, 1984,* 39-44. Amsterdam: Elsevier Science Publishers, 1985.

Knabe, K. (1995). Apple guide: A case study in user-aided design of online help. *Proceedings of the Conference on Human Factors in Computing Systems, CHI-95, Volume 2, Denver, CO, USA, May 7-11, 1995,* 286-287.

Lewis, C., Polson, P., Wharton, C. & Rieman, J. (1990). Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces. *Proceedings of the Conference on Human Factors in Computing Systems, CHI-90, Seattle, WA, USA, April 1-5, 1990,* 235-241.

Nielsen, J. (1993). *Usability Engineering*. Boston: Academic Press.

Norman, D.A. (1981). Categorization of action slips. *Psychological Review, 88,* 1-15.

Norman, D.A. (1983). Some observations on mental models. In: D. Gentner and A.L. Stevens (Eds.): *Mental Models*. Hillsdale, NJ: Erlbaum.

Pintelon, L., Gelders, L. & Puyvelde, F. van (1997). *Maintenance Management*. Leuven: Acco.

Reason, J.T. (1990). *Human Error.* Cambridge: Cambridge University Press.

Sellen, A.J. (1994). Detection of everyday errors. *Applied Psychology: An International Review, 43(4),* 475-498.

Westendorp, P. (1988). Gebruiksaanwijzingen als instructie en naslagwerk: Hoe bereik je zowel lezers als zoekers. *Communicatief, 1(1),* 33-43.

Wright, P. (1983). Manual dexterity: A user-oriented approach to creating computer documentation. *Proceedings of the Conference on Human Factors in Computing Systems, CHI-83, Boston, MA, USA, December 12-15, 1983*, 11-18.