Digitization of the Line Maintenance Checklist:

Analyzing Requirements and the Innovation Process

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Abstract
At Saab in Linköping, flight technicians carry their most valuable technical information with them to clear aircrafts for take-off and check them after landing. A binder holds the technical information: the *Line Maintenance Checklist* (LMC). Due to updates, the text in the LMC is small and the readability is low. To solve this, the viability of a digitized LMC and what requirements exist on both a current and future LMC have been extracted from interviews and observations, through an affinity diagram, creating personas and scenarios. Subsequent sketching lead to a prototype that was evaluated and improved. Requirements included memory support in rare procedures and support by pictures or further information not included in LMC. A digitized LMC should be developed in-house to be adopted quickly and without issues. Further studies should delve into the hardware requirements of a digitized LMC.

1 Introduction

Flight technicians working with the JAS 39 Gripen at Saab, in Linköping, carry their most valuable technical information with them in a binder, the *Line maintenance checklist* (LMC). It consists of A6 sized pages in plastic sleeves, and fits in the flight technician's leg pocket. Information in the LMC is updated three or four times per year and every flight technician is responsible for updating their personal LMC. The frequent updates have led to an increase in its thickness due to more information being added. As the binder needs to fit in the flight technicians pocket for easy transportation and accessibility, text with small font size and a cramped layout is used to keep the amount of pages down. This is a short term solution that leads to low readability.

Before the pages are printed, information is stored as PDF files which are interconnected by hyperlinks to aid navigation while working at a computer. This functionality is lost when the files are printed.

The problems mentioned above have led Saab looking for solutions for how to ease navigation through LMC and be able to fit more information into it. One possible solution is to digitize the LMC. Since it must be available to the technicians at all times, should an accident occur, a digital version's accessibility would have to equal the current LMC's handiness. Additionally, as the technicians update their personal copy of the LMC, they always know if they are using the latest version. This must also apply to the digital version in order for the technicians to trust the information's validity.

Studies on the digitization of instructions have found that using digitized work cards (similar to the instructions in the LMC) can be a significant improvement to paper-based work cards. Furthermore, computer-based work cards can surmount limitations of paper-based ones (Drury, Patel, & Prabhu, 2000).

In context of the domain and its challenges, Saab wants to know if a digital version is possible and what the requirements on the LMC are. To review this area, the requirements will be formalized using ethnographic methods, leading up to a digital prototype and, later on, an evaluation of said prototype.

Adopting a new innovation such as a digital LMC may lead to unforeseen consequences, not only for the flight technicians who would use it in their daily activities, but also for the structure of the organization surrounding it, especially the people that develop and maintain it. Knowledge and information gaps can emerge between those who adopt the innovation early and those who do not (Rogers, 2003). Because of this, adoption should be as quick as possible. This area of research is called *diffusion of innovations* and is highly relevant for this project to ensure that possible effects of adopting a digital version are discovered and acknowledged as well as developing a product with adoption rates in mind.

Apart from Saab's needs, the connection between user-centered design and diffusion of innovations will be explored. This project aims to discuss requirements on LMC both now and in the future. Also, it aims to understand the possible effects of introducing a digital version of the LMC into the organization.

1.1 Research questions

The goals of the project lead up to the three research questions: (1) What are the requirements for a digital solution for LMC? (2) What factors of the organization affect the adoption rate of a digital solution of LMC? (3) How would a digital solution for LMC affect personnel involved in the maintenance and distribution of it at Saab Linköping?

1.2 Delimitations

This study will exclusively focus on Saab in Linköping and primarily the flight test department even though JAS 39 Gripen is also used on other locations in Sweden and abroad. The main reasons for this are time limitations and that a study of larger magnitude would fall outside the scope of the course.

Another delimitation is that the choice of hardware for the final product will not be discussed, due to the same reasons. However, the need for a product of similar size to the current LMC binder will be accounted for.

2 Relevant concepts from literature

This section presents literature relevant for this project. The literature used comes from different disciplines, and is separated into two sections. The first explains theories relevant to the design and evaluation of the prototype. The second outlines key concepts from research on diffusion of innovations.

2.1 Design

Arvola (2014) writes that design should be human-centered since a design becomes valuable when it comes into use. If a product is never put to use, the development process turns out to be wasted time and money. Therefore, it is crucial to design a product with its intended users in mind to ensure that the product is beneficial and useful for them. According to ISO 9241-210 (2010), human-centered design is an iterative process that involves planning, understanding of the situation, specifying what the user wants, producing a design and evaluating the results. After evaluating, the process may start over, from getting a new understanding of the situation to iterating until a satisfying result is achieved.

Affinity diagrams are, according to Arvola (2014) a way to organize qualitative data from several group members. It is important to create the diagram shortly after the interviews and observations to ensure that the group members still remember their findings and reflections clearly. After this, the findings are arranged into categories based on their content.

Designing unequivocally with the user's wants and needs in mind can be difficult as group members may have varying interpretations of the user's situation. In order for everyone to design for the same user, a persona can be used. A persona is a character with combined traits and personalities from the various users that have been observed and interviewed. The character is created with a name, background, wants and needs. It should be created to be as lively and specific as possible, which makes it easy to talk about and a powerful communication tool for the designers. The persona also needs an environment in which it comes to life. This environment is called a scenario and can be seen as a story where the character is described in a specific situation (Arvola, 2014).

With the persona and a specific scenario as base, prototypes are created. The prototypes are used to test design ideas in practice, without them it can be hard to specify requirements on the planned product or service (Arvola, 2014). Additionally, working with prototypes is important since they, together with user testing, can reveal the user experience of different design decisions Arvola (2014).

In order to evaluate design ideas implemented in a prototype several methods can be used. A frequently used tool is the *System Usability Scale* (SUS). It was developed as a response to the requirements of a cost efficient of evaluating the usability of systems within an industrial context. (Brooke, 1996). The think-aloud test is another commonly used method. According to Lewis and Rieman (1993), it can be used to get the test persons' initial thoughts about the design and usability. The user is encouraged to talk out loud while performing a predefined task (Lewis & Rieman, 1993). Arvola (2014) emphasizes the importance of identifying the problems the user encounters while performing the task. A think-aloud test may also include discussion of interesting aspects, together with the users' overall impression and suggestions for improvement of the tested product or system (Arvola, 2014).

2.2 Diffusion of innovations

The process of diffusion can often be a slow one – it can take many years for an innovation to become adopted and accepted. In order to speed up diffusion one needs to be aware of the factors that affect the rate of adoption. Basic understanding of how the innovation process develops is also beneficial, particularly for discovering possible effects on the organization.

According to Rogers (2003), the factor that explains most of the variance in adoption rates is the innovation's five perceived attributes*: relative advantage, compatibility, complexity, trialability and observability.* These attributes, along with others (e.g. perceived usefulness), have been examined in a wide range of diffusion studies and have been confirmed to be some of the most important factors for adoption rate (Al-Jabri & Sohail, 2012; Burn, Gemoets, Jacquez, & Mahmood, 2000; Gambatese & Hallowell, 2011; Liu & Li, 2010).

Relative advantage is defined as to what extent the new innovation is perceived as being better than the one it replaces. *Compatibility* is the degree to which an innovation is perceived as consistent with the existing values, beliefs, habits and experience of its user. *Complexity* refers to perceived difficulty in using and understanding the innovation. *Trialability* is defined as to what extent an innovation may be experimented with or tried out. *Observability* is defined as to which degree the results of an innovation are visible to others.

Relative advantage, compatibility and trialability are positively related to the adoption rate while complexity is negatively related to it. (Rogers, 2003)

In addition to the attributes, a *champion* often plays an important role in an organization's innovation process (Rogers, 2003). A champion is a charismatic individual who uses his or her influence to support an innovation and usually has three valuable qualities: they (1) occupy a key linking position in their organization, (2) possess analytical and intuitive skills in understanding individuals' aspirations, and (3) demonstrate fine interpersonal and negotiating skills in working with other people in their organization.

Innovations are often separated into technical innovations (technologies, products and services) and administrative innovations (new procedures, policies and organizational forms), Van de Ven, Polley, Garud, and Venkataraman state, however, that most innovations include both technical and administrative components (Van de Ven, Polley, Garud, & Venkataraman, 1999).

The importance of the relationship between technical and administrative innovations is highlighted by Damanpour and Evan (1984). They examined the rate of adoption of both technical and administrative innovations in public libraries and found that the adoption of technical innovations is facilitated by the adoption of administrative ones. This means that not only the attributes of the innovation itself, or champions, affect the rate of adoption, but the organization's administrative innovations will also affect its ability to adopt new technical innovations.

The innovation process concerns the path that an innovation takes – from idea generation to putting that innovation to use. Common for all diffusion processes are (1) the innovation, (2) communication channels and (3) a social system. These three elements are central to the diffusion process which develops in different stages over time. How the innovation diffuses highly depends on the structure of the social system and its communication channels. Rogers (2003)

3 Method

To gain an understanding of the requirements on both a future digital LMC and the current LMC, several methods were used. Since the requirements on LMC are subjective and the experimenters had little insight into the domain, an ethnographic approach was the best choice. In contrast to doing a quantitative study, the answers would be used to delve into what the technicians found most important.

First, the experimenters observed the use of the LMC and conducted an unstructured interview with the turnaround service manager and two technicians. Field notes about who said what, the location and the technicians' actions were carefully conducted (Aspers, 2010).

Interview questions were developed from the insights gained during the observation and initial interviews. Before interviews began each participant gave their consent to participate in the study and was informed about their anonymity, as well as the purpose of the research. The interviews were semi structured and recorded after the consent of the interviewee.

The results from the interviews and observations were compiled by the experimenters. In a subsequent session, an affinity diagram was developed according to the guidelines in Arvola (2014). After this, a persona and four scenarios were created to lay the groundwork for the tasks and requirements the prototype should support. The prototype was designed using user interface guidelines from Tidwell (2011) and was evaluated in accordance with the workflow of human-centered design described in section 2.1. Both the prototype and the evaluation are seen as methods to further explore the requirements on the LMC.

The prototype was evaluated at Saab in Linköping at the flight test department and at the delivery and modification hangar with a total of five users. The users worked as flight technicians or in technical support, with an average work experience of 26.5 years. The evaluations were conducted with one user at a time, for a maximum time of 30 minutes. Each session started with the experimenters introducing themselves and the project. The process and purpose of a think-aloud test were described and testing began after receiving informed consent. The first screen of the prototype was showed and the user was asked to answer some first impression questions. After that, the user navigated the prototype to solve the two tasks, which were presented one at a time. The user's reaction to and path through the prototype was recorded by the secretary.

When the tasks were completed, the user was given a form to document age, work title, years of experience and some information about preferred operating systems for smart phone, tablet and computer. Lastly, the user filled out a SUS survey, based on the version found in Sauro & Lewis (2012), translated to Swedish.

The results of the evaluation were used to create an improved prototype.

4 Results

The data gathered from interviews and observations were used both as a foundation for developing the prototype and to map out the organizational structure around the LMC.

The affinity diagram used to organize the data showed that the most central aspect of the LMC is its key role in keeping the aircrafts in the air. The technicians likened it to the Bible and said that it always needs to be with them on the line. It is their biggest support and functions as a memory list. Another important aspect of the LMC was the information. Many of the fault codes that may occur during turnarounds are not explained in the LMC and need to be looked up elsewhere. Related to this is the readability of the LMC, which is low due to the small font size.

The categories from the affinity diagram were formalized into a persona, which “came to life” in two different scenarios. The first scenario describes the aircraft turnaround process and the flight technician being unsure of how to perform a certain action described in the LMC. The second scenario describes the flight technician performing an acceptance check and wanting to look up an encountered fault code.

When making the prototype, focus was placed on keeping it consistent with how the current version looks, in order to make it easier for the technicians to understand. Additionally, to improving readability and exploring options to simplify finding information. The main functionalities implemented to support this was increased font size, the ability to search for fault codes, as well as being able to write personal notes.

4.1 Evaluation of the prototype

The results of the evaluation revealed a great enthusiasm for a digital LMC but also showed where there is room for improvement in the prototype’s design.

Every user liked the concept of the prototype. It was described with words such as familiar, really clever, handy and as being a great first step to a digital LMC. The home page containing the menu were said to be simple, easy to use, and brilliant. Users appreciated its resemblance to the original design of the LMC binder. They also liked the idea of being able to search for fault codes and wished for a global search function. The idea of being able to add personal notes was also well received. Navigating the prototype was an area where there is room for improvement. Users struggled to get back to the main menu, accessed by swiping vertically from the top of the screen, after entering a category.

Despite issues with navigation, the overall SUS score mean was 80.5, with a standard deviation of 7.79.

4.2 Organizational structure around the LMC

The data gathered from interviews and observations was used to map the flow of information and organizational structure around the LMC.

Updates of the LMC is ordered by Försvarets materialverk (FMV) and produced by the technical information department at Saab. Before being sent to technicians, the information needs to be approved both internally by Saab and then verified by FMV. If it is not approved, it will propagate back to the technical writers. When finished, the LMC is distributed on paper and on CD:s by mail.

When a new version of the LMC arrives at the flight test department at Saab Linköping, administrators forward it to technicians’ post boxes and informs them via email that an update has arrived. The technicians are responsible for updating their binders and send a receipt to the administrators when the update is complete. Inspections are sometimes carried out by administrators to make sure that everyone is using the latest version.

If a technician finds an error or notice that there can be improvements to the LMC, they fill out a form and send it to administrators by email. The administrator will register the ticket in a database and a group of engineers investigate all incoming tickets every day. If there is no emergency, there will be further investigation by personnel within the relevant area. The investigators create a recommendation of how to solve the issue and send it to FMV. Because FMV is the client, they decide how to solve the issue based on the recommendation from Saab.

5 Discussion

Initially, some concerns about digitizing the LMC arose, the high demands for availability and reliability mentioned in section 1 was the most pressing concern. A digital device in contrast to the paper version needs electricity to run. Because of the availability requirement, a situation where the LMC is needed but shuts down due to low battery levels cannot be allowed to happen. This situation can be avoided by having a device that allows for easy replacement of batteries or that a paper version is available in the hangar as a backup. Since the hardware aspect of the digital version has not been considered in this study we cannot say whether battery replacement is a plausible solution or not. Our concerns regarding this issue were lowered by the fact that the technicians have very firm routines regarding the LMC today and take their job very seriously. Therefore, there will most likely be a policy for all flight technicians to keep their LMC charged, much in the same way that they now are required to always have it with them and keep it updated.

The evaluation of the prototype showed a wide range of results. Firstly, the SUS mean was 80.5 (SD = 7.79), which shows usability above Sauro’s (2011) score for above average usability: 68. In contrast, the results from the think-aloud test showed some troubles with the navigation of the prototype. However, users liked the concept presented by the prototype and could see themselves using it in the future. This might have led to that the users rated the prototype high to ensure that the idea of a future digital LMC was not discarded.

In the second, improved, prototype the placement of the menu was restructured, a global search function added and navigation was made easier. Our findings show that the concept of a digital LMC is viable but the improved prototype should be tested as well.

Developing the digital LMC at Saab would enable close communication with the users, a central part of the human-centered design used in this study. It would also help to improve the trialability and compatibility as well as reducing complexity of the innovation. The trialability would increase if the technicians could test different functions of the product during development, in line with human-centered design used in this study. Also, regarding the complexity of the innovation, the evaluation in 4.1 showed that the technicians thought the navigation of the prototype was difficult. However, since the technicians like the concept of a digital LMC the relative advantage would likely outweigh the perceived complexity of this early prototype.

Finding people who can act as champions will help with the adoption rate. From our observations and interviews we concluded that the role of champion fit the turnaround service manager well. He is supervisor for the technician and their closest contact should any problems arise in the turnaround process. Also, he is the connection between flight test and support and services.

As stated in 2.2, an organizations' administrative innovations can affect adoption rates of innovations. We propose that during the implementation of a digital version, a group that provides support to the flight technicians will be beneficial. It is possible that this kind of work could be handled by Saabs internal IT-support but research on innovations reveal that the adoption rate would likely improve if it was handled by a group that is more familiar with the users' situation (Rogers, 2003). If the flight technicians are able to communicate with someone they know who is knowledgeable of their work procedures and environment, this will likely reduce perceived complexity and improve the rate of adoption. Because of this we suggest that support for the digital version should be handled by an administrative group at the flight test department, at least in the beginning of the implementation process.

Another area that can be changed due to the potentials of a digital LMC is when a technician notices an error or possible improvement in the LMC, as mention in section 4.2. The current procedure for this involves the technician filling out a form on a computer and sending it by email to the administrative department. A new possible procedure for this is to handle it directly in the LMC. Writing long texts on a tablet is far from optimal, instead we propose that the technician chooses different options from drop down menus in a wizard-like environment.

The previous two proposals have not been examined thoroughly in this study because of time limitations and scope of the study. Therefore, we cannot say for certain whether these proposals will work or not. It also depends on how the digital LMC will function. However, we can say a change is likely to take place in these areas thanks to new capabilities of a digital platform.

Qualitative methods were used in the report aiming to understand the users' behavior. To answer the first research question, a design approach was adopted. From observation and interviews, the results were analyzed thematically using the Affinity Diagram methodology. Persona and scenarios were used as a stepping stone from this to prototyping. Finally, the prototype was tested and evaluated. With the aim to gather the requirements on LMC, the design approach was valuable. To be able to generalize the prototype's performance, quantitative methods were used. The combination of methods to gather the requirements on LMC was valuable. If only qualitative methods would have been used, it would be difficult to compare the prototype's performance to a general standard. Arvola (2014) writes that to find out more from the data, apart from an Affinity Diagram, concept maps, a use quality analysis with a prism, IPA analysis and task analysis could have been used. None of these methods aim to *illustrate* the data in the form of for example personas to lift key aspects, which is why personas were used instead.

One of the personas that was created, the novice technician, was not used when sketching due to lack of time. Further, this persona was not created from the results of observations and interviews since there are no novice technicians at Saab Linköping. Thus, this persona falls outside the delimitations of the project. It is however of interest to consider how the final design might be received by a novice technician since it at some point will be used by a novice technician. This persona can be used in further studies, interviews and observations of novice technicians are essential to gain knowledge of how they use the LMC. Thereafter the persona can be updated and result in a clearer picture of a novice technicians' requirements on the digital LMC.

If the project did not have a design approach, more time would have been devoted to analyzing the future adoption rate and the effects a digital LMC would have on personnel involved in the maintenance and distribution of it. However, some requirements on the LMC were found by evaluating the prototype and would not have been discovered through interviews and observations alone.

Since we were unable to interview personnel at FMV we cannot get the full picture of what the organizational structure surrounding the development, distribution and maintenance of the LMC looks like. Much of the information regarding this might also be unavailable to us because of security reasons, we can therefore not claim that our view of the organizational structure around the LMC is complete but we do feel that we have a clear enough picture to be able to see where changes might occur, should the LMC become digitized.

6 Conclusion

The results showed that there are requirements on the hardware of a digital LMC. This includes that it needs to be charged at all times, sturdy, available to use in different lighting and not too heavy or too big to fit in the leg pocket. Other than the physical requirements on it, there are two main requirements. The first is memory support, just like the current version. It is important that this function is transferred to a digital LMC so that it is as available as the current LMC. Relating to this, the function of the digital LMC should be compatible with the current LMC, also to increase the rate of adoption. The other requirement on LMC is what the flight technicians lacked in their current work tasks; further support on the line. This includes pictures, but most importantly; the ability to search for key terms and fault codes.

Several factors influence the rate of adoption. One recommendation that will positively affect the adoption rate of a digital LMC is to develop the product in-house. Saab should have in mind the champion's role and who or which people might be the champions. Important to notice are both the technical and the administrative innovation that might come to be. An administrative change that would facilitate LMC:s adoption rate is to create a group assistance team. Also, to avoid complexity, a clear structure of LMC developed in accordance with user interface design rules and with the flight technicians in mind is crucial.

Further studies regarding digitization of the LMC could include the hardware aspect of a digital LMC, especially in the military units using the LMC, and looking into FMV:s organizational structure to find touch points to develop.

Acknowledgements

This project would not have been possible without Karin Hörberg, Stefan Gustafson and Saab. We are all very glad to have been able to work in this project and would like to thank them for helping us get in contact with key persons, contributing with expertize and being gracious hosts at Saab.

We would like to extend a special thank you to Jens Alfredsson and Tim Overkamp for supervising this group and guiding us throughout the process. We are also grateful for the opportunity to be a part of the mentor company program, arranged by Mattias Arvola and Tim Overkamp.

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