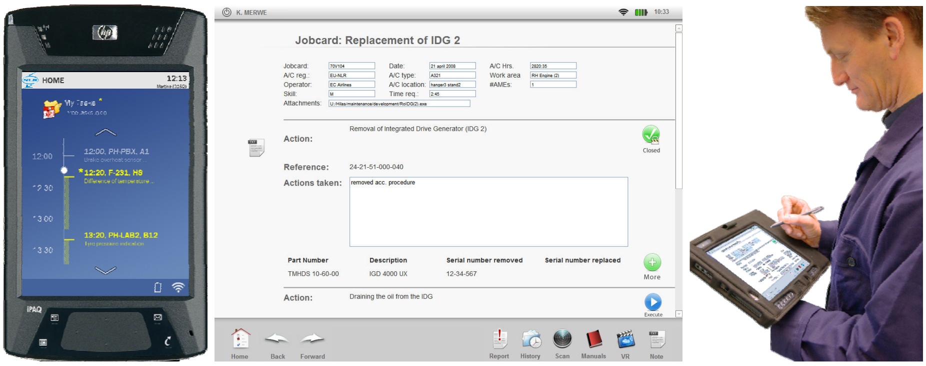
Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

PAMELA, a portable solution for workflow support and human factors feedback in the aircraft maintenance environment



Problem area

Earlier research aimed at the identification of human factors issues in the aircraft maintenance environment yielded a better understanding of amongst others the issues related to documentation use and task support. It clearly identified the co-existence of formal and informal ways of working, potentially leading to unsafe situations.

The use of nomadic devices (portable computer tools using a wireless connection, ruggedized for the harsh maintenance environment) is expected to improve this situation in two ways: First the information is brought to the work floor in an improved and task-oriented fashion, incorporating the workflow structure of maintenance tasks. Second, it can be used to collect performance data and human factors information as a crucial information source regarding the current mismatch of formal processes and the actual way of working. As such it can play a vital role in organisational learning processes within and across organisations.

Description of work

The so-called PAMELA concept (Personal Aid for Maintenance Engineers in Line operAtions) was developed, comprising a set of task support functions to make the task execution process more efficient. For a number of functions in this concept, graphical user interface designs were made as part of the EC co-funded projects TATEM and HILAS. The TATEM project focuses on the process orientation of the future maintenance system and the HILAS project on the

Report no.
NLR-TP-2008-666

Author(s)
M.Y. Hakkeling-Mesland
G.K. van de Merwe

Report classification
UNCLASSIFIED

Date
October 2008

Knowledge area(s)
Aeronautical Human Factors,
Training & Flight Simulation
Safety & Security

Descriptor(s)
Aircraft maintenance
Human Factors
Nomadic computer devices
User interface design
Workflow support
Organisational learning

This report is based on a presentation held at the Human Factors and Ergonomics Society (HFES) European Chapter annual meeting, Soesterberg (the Netherlands), 15-17 October, 2008.

human element in the lifecycle of aviation systems. These distinct project scopes allowed for different yet complementary viewpoints and functionalities to explore and develop under one coordinated concept.

Results and conclusions

As part of TATEM, a functional PDA user interface prototype was developed, with use of NLRs rapid prototyping tool Vincent. This served the main purpose of demonstrating the possibility of the TATEM process oriented approach.
As part of HILAS an HTML interface demonstration for a Tablet PC was developed. In the HILAS project, the PAMELA concept plays a role at both ends of the project scope. On one hand is serves as a means to collect information ("sensor") for organisational improvement and on the other end it is part of the improved maintenance situation HILAS aims at, providing solutions for previously identified human factors issues.
User trials undertaken as part of HILAS provided a general positive response, particularly in relation to anticipated time savings. The user interface design was rated very positive, both with respect to the information provided and the workflow elements incorporated. In addition, the data gathering functions were appreciated provided privacy considerations would be taken into account.
The TATEM and HILAS projects are currently still ongoing and the user interface designs are being further developed and integrated.

Applicability

The user interfaces were developed for the aircraft maintenance domain but could be transferred to other (maintenance) domains where the use of (written) procedures plays an important role. The concept of (active) human factors and performance based information gathering on the work floor for organisational improvement purposes would be applicable to many domains and organisations, for instance to manufacturers, particularly if digital workflow support systems are already being used.

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PAMELA, a portable solution for workflow support and human factors feedback in the aircraft maintenance environment

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Customer	NLR
Contract number	----
Owner	NLR
Division NLR	Air Transport
Distribution	Unlimited
Classification of title	Unclassified
	October 2008

Approved by:

Author	Reviewer	Managing department
	13-11-2008	

Summary

This paper describes the NLR PAMELA (Personal Aid for Maintenance Engineers in Line operAtions) concept and the graphical user interface design of some aspects of it, developed in the EC co-funded projects TATEM and HILAS. The PAMELA concept is based on the use of nomadic computer devices to provide workflow support to aircraft maintenance engineers. It includes a set of functions for potential efficiency improvement, error reduction and the collection of performance data and human factors information. Earlier research in this area yielded a better understanding of the issues related to documentation use and task support requirements. The structure of the concept is modular, thus allowing for supplementary functions to be added.
The TATEM project focuses on the process orientation of the future maintenance system and the HILAS project on the human element in the lifecycle of aviation systems. These distinct project scopes allowed for different yet complementary viewpoints and functionalities to explore and develop under one coordinated concept. Due to the generic character of the EC projects, the project results are not expected to be *the* solution for one specific maintenance organisation, but sets of elements can be taken out for further customisation by individual end-user parties.

Contents

Abbreviations

AME	aircraft maintenance engineer
EC	European Commission
HILAS	Human Integration into the Life cycle of Aviation Systems
HILAS KMS	Knowledge Management System developed as part of the HILAS project
PAMELA	Personal Aid for Maintenance Engineers in Line operAtions
PSS	Portable Support System
RFID	radio frequency identification
TATEM	Technologies And Techniques for nEw Maintenance concepts
VR	virtual reality

1 Introduction

Previous research has identified a number of human factors issues in the aircraft maintenance environment, of which a large number were related to the use of procedures and task documentation, as described by Van Avermaete and Hakkeling-Mesland (2001). Many of the results pointed out that a better form of task-support was needed in order to improve both safety and efficiency. Two main indicators as derived from these studies, which were based on a number of surveys done in maintenance organisations across the EU, supported this conclusion: the high figures for non-compliance to task procedures (up to 34% of the total number of cases), and the omnipresent use of so-called ‘black books’, illegal and personal note books, containing notes for later reference. Deficiencies in the content of procedures (e.g. there are easier and quicker ways) and the cumbersome accessibility of the information with respect to the actual way of working were often cited as motivation for this behaviour. Although a strong commitment to safety was observed, so was a double standard that allowed the official and actual way of working to exist side by side.

When unofficial ways of working take place, this clearly has an impact on safety. Safety systems (e.g. sign-off for having completed the work according to procedure) are being by-passed and the organisation will not be able to monitor what actually happens. In addition, operational feedback on the mismatch between the prescribed and actual way of working will not become available. This would potentially be relevant information for the improvement of technical and organisational procedures and processes. Ironically, the high sense of safety that was experienced among maintenance personnel was found to contribute to this situation occurring. Aircraft Maintenance Engineers (AMEs) were found to be inclined to take on additional tasks on their own discretion for safety reasons (e.g. to perform additional inspections of problematic parts). This would add to an already high workload situation and lead to (perceived) high time pressures. Based on the same sense of safety, it is therefore expected that AMEs will not be unwilling to follow the task instructions to the letter, if the required information for the task is provided in a more efficient manner, at the right time. A functional feedback and improvement system, effectively using comments from the work floor to adapt procedures and processes, potentially would add to this. Nomadic computer devices could facilitate both information consultation and feedback provision and as such would contribute to an overall objective of continuous safety and efficiency improvement.

The PAMELA concept is based on the use of nomadic computer devices. Its main goals are to provide workflow support to AMEs and simultaneously capture human factors and performance related data and information. The use of nomadic devices will directly improve the on-the-job availability of the task information. In addition, a task oriented interface design is applied, which, combined with context based linkage of information, is expected to improve the accessibility of the information. The PAMELA concept comprises the following three basic elements: First, access to the maintenance information to perform the task. Second, additional functions relevant for task execution, such as links to relevant support departments and automation of administrative actions. And third, functionality for data collection and provision of feedback. The modular set-up of these functions allows for future extensions to be added.

The PAMELA concept is being further developed in the ongoing EC co-funded projects TATEM (Technologies And Techniques for nEw Maintenance concepts) and HILAS (Human Integration into the Life cycle of Aviation Systems). Both projects have a specific outlook on the future maintenance system and potential improvements. The TATEM project focuses on new technologies for health managed aircraft and the process orientation of the future maintenance system whereas the HILAS project focuses on the human element in the lifecycle of aviation systems. NLR's role in both projects was the development of a selection of user interface design elements that, although based on distinct project scopes, fit in with the overall PAMELA concept.

2 Description of the NLR PAMELA concept

PAMELA is meant as a personal aid. Based on previous research, the hardware of the PAMELA concept comprises of a suite of devices appropriate for the various working conditions that occur in aircraft maintenance, such as a PDA, a small laptop or a large screen display. Input mechanisms are either a hard or soft keyboard, stylus (touch screen) or voice control. The hardware should be ruggedized to outlast the harsh maintenance environment. Ideally, in the future situation, an AME should be able to pick up the hardware device most appropriate for the task to be executed. Application of the same interface design philosophy regarding user interaction and 'look and feel' for each of the devices will allow for smooth conversions between devices used for different tasks. The equipment is connected through a wireless network link with a data kernel containing the up to date versions of all relevant information.

Main users of PAMELA are AMEs directly involved in the execution of maintenance tasks. Either individual AMEs or two or more AMEs working together on a task should be able to use the system. The concept is aimed at the future maintenance situation, where the current distinction between line and base maintenance is expected to decrease. Fewer long maintenance visits and more scheduled maintenance executed at night are expected to characterize the future situation.

The core function of the PAMELA system is to assist AMEs in the preparation and execution of the maintenance tasks (see Figure 1). This is achieved by providing technical task information (e.g. Maintenance Manual, parts catalogues, Service Bulletins), as well as a link to onboard and in-flight reported fault information (e.g. to the Built in Test Equipment system or a Digital Electronic Flight Bag). Around this core, additional task support functions have been defined with the aim to improve efficiency and safety (e.g. through error reduction). A set of administrative functions allows the accumulation of digital information related to the execution of the task. This type of information consists for example of sign-off, task handover, non-conformance, damage and incident information which is currently captured on paper forms. A planning function, linking to the planning department, informs the AME directly of the tasks to be executed in the near future (e.g. the shift). Likewise, links to shop and stock database systems are provided to allow checking the availability of tools and parts and ordering them online. Furthermore a notes function is included for digital notes to be made comparable to the described current 'black books' either for personal use or to share across the organisation. These notes are digitally linked to the official maintenance documentation they relate to and stored in a database. As such they are available for review and editing by the organisation (e.g. the Engineering department) and make up a much more controlled information source.

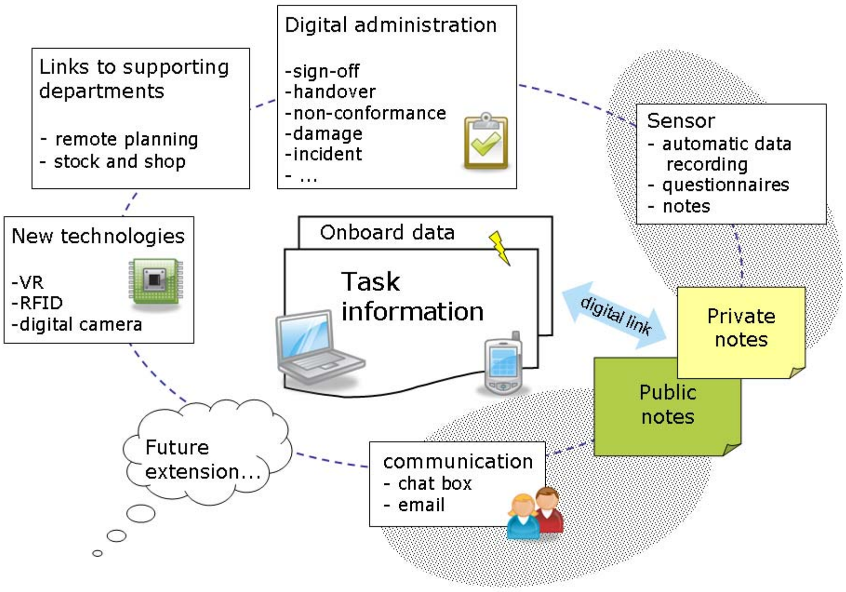

Figure 1 Schematic presentation of the PAMELA concept

Three technologies for performance support are included in the concept: Virtual Reality (VR), Radio Frequency Identification (RFID) and a digital camera. VR can support the visualisation of the task, including human factors information, which enables previewing and rehearsing tasks and to provide on-the-job training. RFID technology can be used for recognition of specific parts or equipment. The RFID information can serve as a quick reference to related information, as such omitting for manual data entry (errors). The digital camera can be used for documentation purposes and to facilitate distant consultation, for example in case of damage.

For a team of AMEs additional functions for information sharing are included in the concept. These allow for consultation of other engineers, comparable to a chat box or email application. Furthermore notes and experiences can be shared, for example by making notes publically available. Functionality to overview the status of different tasks executed in parallel on the same aircraft is expected to improve shared situation awareness.

At the level of the maintenance organisation PAMELA serves as a ‘sensor’ to collect human factors and performance related information from the work floor. This is achieved in three ways. First, data is automatically recorded whilst the tool is being used. For example data could be captured on the information sources accessed and the duration of consultation. Second, information is collected with the use of (short) digital questionnaires to be filled-in by the user, either to voluntarily provide feedback or upon request by the system at pre-defined instances. Third, review of the digital notes made through the notes function will provide the organisation with feedback on the actual way of working. The collected information needs review for validity and relevance and could be used as input for improvement of procedures and processes. The development of the tools for data management and analysis and the organisational system to utilise the data for such purposes is outside the scope of PAMELA. This is however taken on as part of the HILAS project, as described by Ward and McDonald (2007).

NLR has commenced the user interface design for a number of the above described functions and different hardware devices in a contextual and user-centred manner as part of the TATEM and HILAS projects.

3 PAMELA developments in the TATEM project

3.1 The TATEM maintenance perspective

The TATEM project investigates new technologies and techniques as a means to considerably reduce operators' maintenance related direct operating costs. A health management approach is developed to improve the understanding of the aircraft status. Subsequently fewer costly delays and cancellations are expected that are the result of unscheduled maintenance. In addition TATEM aims to improve the efficiency of both scheduled and unscheduled maintenance through the application of a process-oriented approach. Improvements in relation to personnel and their equipment are based on the introduction of a Portable Support System (PSS) comprising the use of nomadic computer devices and process oriented information application. In short this means the AME has direct access to the information needed at a certain process step, without the need for searching. In Buderath et al. (2008) the TATEM ground crew support system, including the technical data, the implementation and the related operational impact are described in more detail.

3.2 User interface design in TATEM

The TATEM PSS consists of a set of commercial off-the-shelf nomadic computer equipment, including a laptop, PDA and helmet mounted display. The selection was based on a combined approach of applying defined functional and technical specifications and a selected use case. The use case consisted of a troubleshooting task on the brake system where two AMEs had to work together and execute task steps in a sequential manner; one AME was positioned at the landing gear while the other was in the cockpit. The selected PDA contained a 7 inch colour TFT touch display with 480 x 640 pixels resolution in portrait format. As part of TATEM, NLR focussed on the development of a functional PDA user interface prototype using NLR's rapid prototyping tool Vincent (Verhoeven & De Reus, 2004).

The task-centred user interface design was based on the selected use case, fed by inputs from project partners, previous research on PAMELA and current PDA applications. Three main constraints were taken into account. First, the display size of the PDA is very limited and does not allow for full maintenance procedures to be presented. Second, the system needs to be fed with responses from the user during execution of the task, in order to determine the next branch of information to present. Third, the two AMEs working together on the task need to be informed of each others actions and progress. Due to unavailability of the future technical data during the initial interface design phase, the prototype was based on existing technical data (maintenance procedures), adapted to the prospects of the future system and the constraints of the PDA interface.

A number of workflow aspects were incorporated in the interface design to demonstrate its future application: a main menu containing the foreseen main functions of the PDA, a timeline presenting the planned tasks for an AME (Figure 2), pages containing the instructions for the task to be executed and a summary page of the work executed. The latter gives access to a sign-off page using fingerprint identification when a task is completed.

Figure 2 The TATEM PDA presenting the home page and the timeline

The task instructions were rephrased into concrete and short action statements, containing checkboxes or yes/no radio buttons to be ticked by the user. The latter provides necessary feedback for the system to determine which statement to present next. They were split up in logic sets of statements to fit on a page, thus omitting the need for scrolling. An icon in the shape of a green check-mark or a red cross appears in front of the line to indicate if the inputs provided by the user were correct or not, as expected by the system. This gives a quick overview of the status of the task statements on a page: a list of green check-mark icons indicates that the task statements on the page have been completed correctly. When a red cross appears, something may have been omitted or may not be in the correct state for continuation of the task. A 'continue' button appears at the bottom of the page when all the required ticks are set, as such preventing task steps being omitted. Warnings and cautions are implemented in red and orange coloured textboxes that need to be ticked off in order for the user to be able to continue. When ticked they are minimised to one line and can be expanded again for review.

Notes are presented in a green text box that is by default minimised to one line. By ticking it and holding the stylus, the user can expand the box and read the full information. Figure 3 presents a number of the display features described.

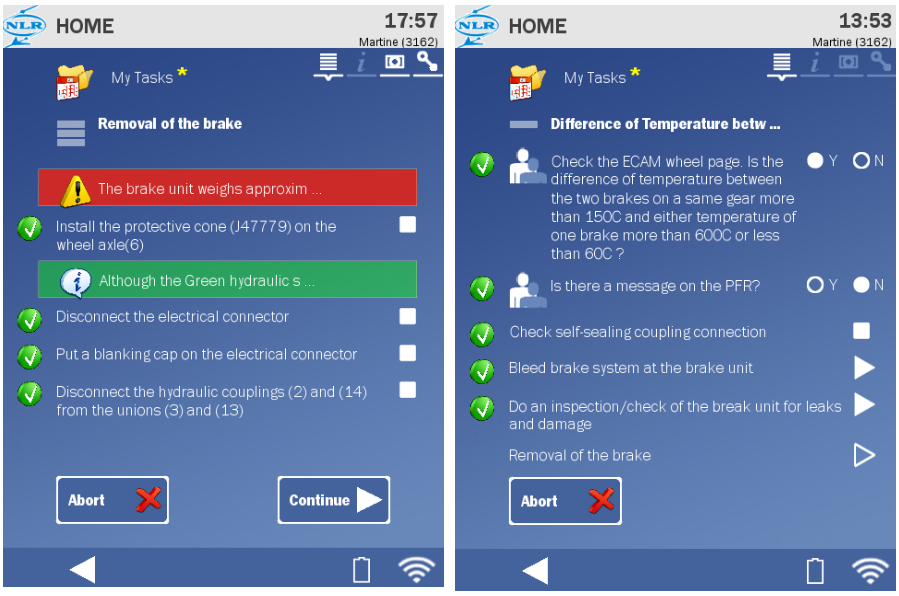

Figure 3 Screenshot of PDA pages during task execution

When two (or in theory more) AMEs work together on a task, they can access the same set of task information together with each others inputs. An icon, resembling two people, is presented in front of a task statement, to indicate that that instruction belongs to the other AME. Both AMEs can make inputs for their co-worker if necessary (e.g. based on radio communication). This option was deliberately not blocked to prevent for unnecessary delays.

4 PAMELA developments in the HILAS project

4.1 Role of PAMELA in the HILAS project

The main goal of the HILAS project is to establish continuous improvements based on the integration and awareness of human factors across the life-cycle of aviation systems. The project is divided into four strands of which one focuses on Maintenance (Ward, et al. 2008). New methodologies and technologies for monitoring and evaluating organisational system performance have been developed as well as a framework for data collection and exchange; the HILAS Knowledge Management System (KMS). As part of HILAS, PAMELA is further developed as one of the tools for the AME which aims to improve performance as well as capture important human factors information. As such, PAMELA plays a role at both ends of the HILAS scope (Figure 4).

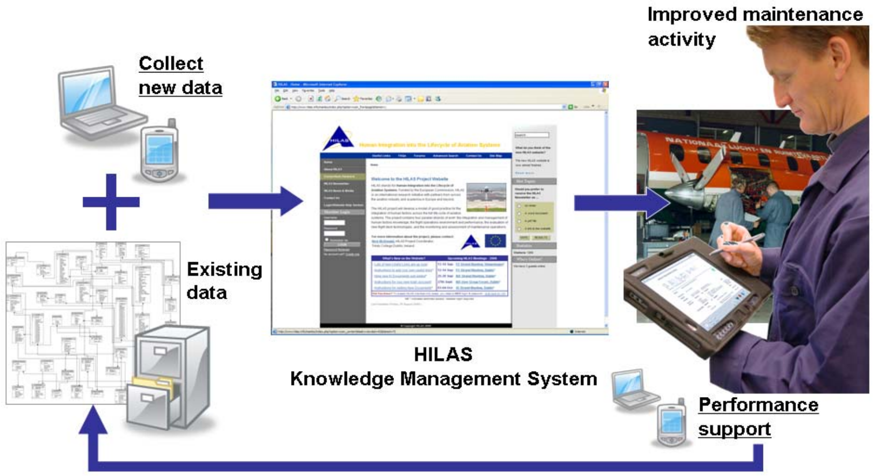

Figure 4 PAMELA as part of the HILAS process

4.2 The user interface design in HILAS

The tool that was developed primarily aims to assist the AME during task preparation and execution. This was demonstrated through the use of a portable device which enables the AME to perform activities in an integrated manner. Currently such activities are distributed throughout the workspace (preparation in the office, task execution at the aircraft, documentation printing at another location). A state-of-the-art ruggedized notebook was chosen as a suitable candidate. With a resolution of 1024 x 768 pixels in landscape format, the device strikes a balance between information density and the readability of the screen. The user interface was developed in HTML format based on current web-standards that allow for an easy integration into most standard operating systems.

A design was chosen which incorporated three distinct areas, a status bar the top, a central content area and a navigation area at the bottom. By placing the navigation bar horizontally at the bottom both left- and right-handed AMEs can navigate the system without obscuring information when buttons are pressed.

The user interface was developed based on previous research on PAMELA, input from consortium partners and field research within the HILAS project. Part of the research focussed on creating a flowchart which structured the task of an AME and served as an input for the user interface development. It was found that the jobcard played a central role in each of the activities of the AME. On the jobcard, tasks are planned, task details are provided, activities are reported, engineers are assigned, tasks are signed off, etcetera.

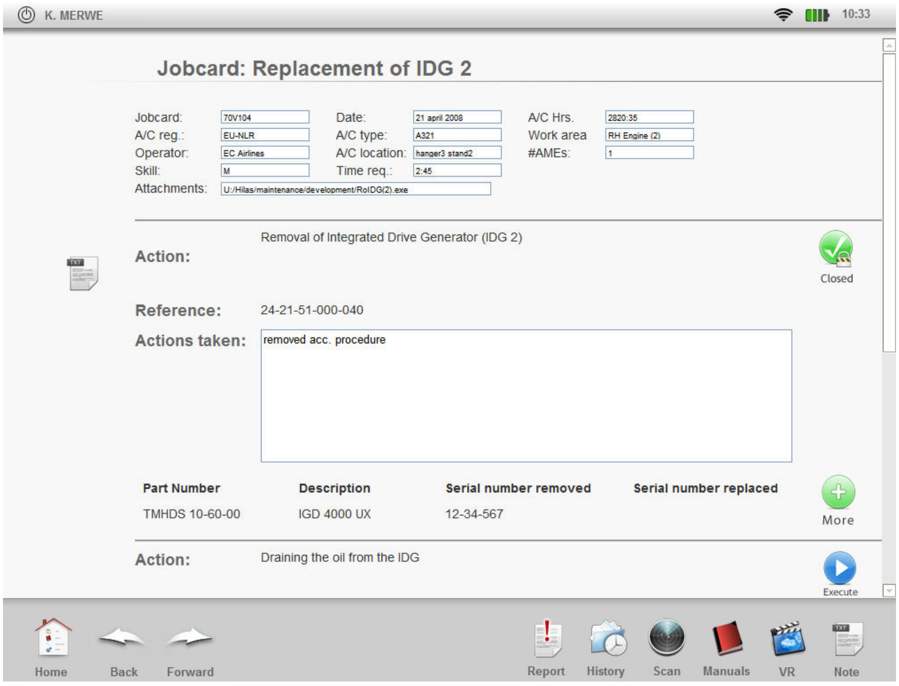

Figure 5 The digital jobcard

The digital jobcard (Figure 5) in PAMELA has areas for pre-determined information about the task and the aircraft that can be populated by the planning department. Other areas are available for information entry by the AME. Information that is pre-determined consists of aircraft type, registration, skill requirement, date, location, expected time required for the task, manuals, tools and material required, etcetera. User input consist of actions taken once finished. The layout of the jobcard changes depending on the progress of task execution; at the start of a task it provides the AME with the required information for preparation and provides access to the task procedures, while during task execution it additionally serves as a data entry tool. Switching between the task procedures and the digital jobcard allows the AME to immediately enter specific actions taken into the jobcard. The information collected on the job card provides a quick overview of the work done and as such facilitates sign-off of the task. After the task has been executed a sign-off occurs through the use of a badge or fingerprint identification.

During task execution the user is presented with the maintenance procedure belonging to that task. The presentation of the procedure is context-based which means that it is presented as a link in the digital jobcard; the AME does not have to search for the correct procedure (correct aircraft type, effectivity, etc.). The procedure is accompanied by a number of checkmarks that are required to be ticked once the related part of the task is executed. This way the engineer is guided through the procedure and stricter adherence is ensured. In addition the checkmarks provide a means for progress monitoring for both the AME and the system, which can for example be used for information provision in case a task handover takes place. At any point during task execution the user has access to a number of support functions such as VR based task models and RFID technology based support.

An RFID function was included to scan RFID tagged equipment in the vicinity, making use of actively transmitting RFID tags, and to select the relevant equipment for the task being executed. The identified part number and serial number of the specific part at hand are used as reference to access the related documentation and equipment information (e.g. part history, EASA form 1). Additionally, they are used to record information on the removed and installed parts on the digital job card, if applicable.

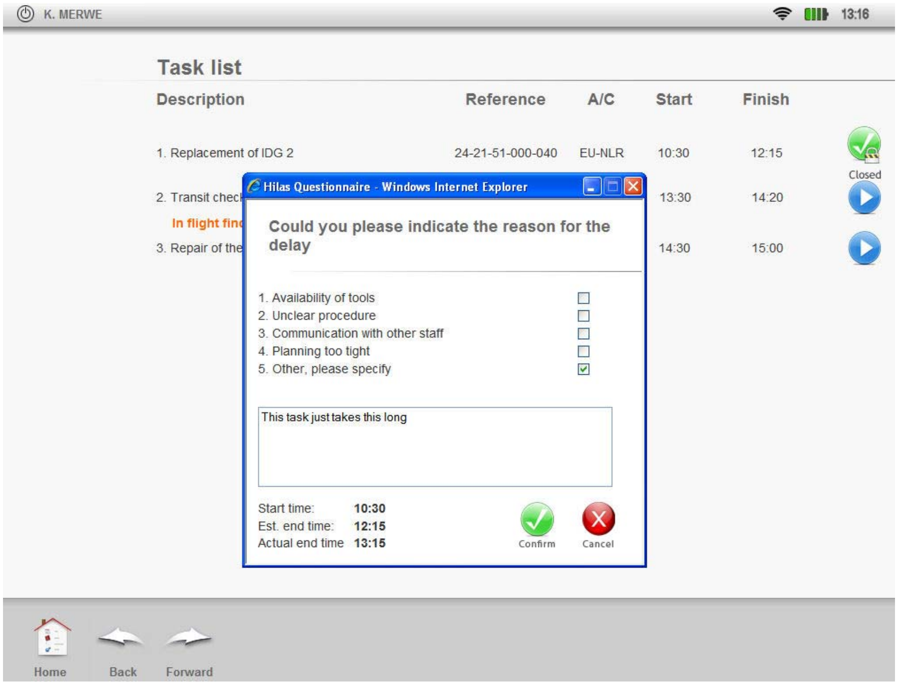

Figure 6 Sensor on the work floor: a digital questionnaire

As part of HILAS, the sensor function of PAMELA was further developed in three ways. First, the information on task progress (timings) as can be collected through the use of the checkmarks is intended to be automatically recorded. Second, during the task execution the user is prompted for information input when specific situations have occurred, for example when a task has taken significantly longer than expected. The causal factors of such overruns are currently not systematically monitored. The AME is presented with a pre-defined list of responses and a free text option for efficient completion of the questionnaire (Figure 6). Third, throughout the procedure the user can add notes to a specific part or the entire procedure. This function allows the user to create personal reminders on how to execute a task as a better controllable digital variant of the current 'black books'. In addition the note system can serve as input for procedure improvements.

5 Discussion and outlook

Both the TATEM and HILAS projects are ongoing and the user interface designs as presented are being further progressed towards functional systems for evaluation. In the TATEM project, a more advanced prototype including an active link to the kernel containing the technical data is being developed, whereas in the HILAS project the interface design is being integrated with additional support functions as developed by other project partners.

Initial evaluation trials showed that AMEs in general respond very positively to the PAMELA concept. Significant improvements related to time savings are expected. An example cited is the reduction of time spent travelling to obtain information, particularly with increased security measures at airports. In the current maintenance situation the PAMELA concept was considered to be more suitable for base than line maintenance. The latter was in general considered too hectic and not structured enough to continuously use a portable support tool for task execution. This is an interesting outcome, given the future situation where more scheduled maintenance is anticipated, for which the PAMELA concept was developed. The user interface design was rated very positively in terms of the amount, relevance, logic and usefulness of the presented information and the workflow structure implemented. Certain elements may need further customisation to cater for differences between organisations. The sensor function was appreciated, provided the organisation would explain its purpose and take privacy considerations into account. Particularly the gathering of data on how long tasks actually take was welcomed as a means to relieve some pressure of unrealistically high expectations off the front line production. AMEs tended to be slightly sceptical about the organisations' willingness to invest in the hardware and worried about the vulnerability of the equipment.

In the TATEM project, the process oriented approach brings major changes to the way AMEs interact with the maintenance documentation. Two topics that were found to require more attention in this future system are the situational awareness and the user's sense of control. In the current situation, maintenance tasks are organised in a hierarchical manner and often executed as subtasks of tasks at a higher level. Links to subtasks, task names and reference numbers are clearly documented and function as hyperlinks in digital versions. While executing the work AMEs follow this structure and actively look up the correct information, relative to the situation at hand. This allows them to build a mental picture of the situation and to be very much involved in the task process. In the process oriented system however, the task instructions are step by step dictated by the system. Potentially this could lead to an experienced lack of situational awareness and sense of control. In the TATEM PDA prototype a certain amount of hierarchical information was provided as a compromise between the current and a full process oriented system.

In the described HILAS prototype the sensor function to directly collect data from the work floor is new and promising. Only a small number of examples of what data and information could be collected in this way have currently been implemented. The HILAS project aims to further demonstrate the use of this information for procedure and process improvement. Gathering data automatically by recording of user interactions to some extent requires adaptation of the user interface (like the checkmarks in the procedures of the HILAS PAMELA design), and as such has an effect on user interaction with the system. This may take additional interaction time and may as such interfere with the work to be done. Further evaluations will have to determine whether this is acceptable and to what extent, both in terms of task performance and related cost.

The PAMELA concept largely focuses on efficiency and safety improvement in the future maintenance context and contains a number of features to help executing the maintenance tasks in a more guided and controlled way. In the TATEM and HILAS projects, some of these features were implemented in the user interface. Initial responses were promising and potential for time savings and efficiency improvement has been identified. Current trends in aircraft maintenance, like the reduction of aircraft downtime intervals, an increase in outsourcing of maintenance leading to less familiar aircraft to be maintained, and a changing population of technicians even further stress the need for performance support tools.

Acknowledgements

The authors would like to acknowledge the European Commission for co-funding both the TATEM and HILAS projects under the 6th Framework Programme and the TATEM and HILAS project partners for their participation in the current work.

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