ELECTRICAL EQUIPMENTS MAINTENANCE TRAINING SYSTEMS APPLYING INTELLIGENT TRAINING AND VIRTUAL REALITY: EVALUATION OF PILOT APPLICATIONS

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SUMMARY

Nowadays Computer Based Training represents a cost effective solution for training of personnel in many sectors of industry and services. This paper reports on the preliminary results of the training needs analysis, user requirements definition and trainee's evaluation of a pilot application concerning maintenance of electrical equipment, a safety related task where more than 300,000 workers are involved European wide.

INTRODUCTION

Maintenance and repair of artefacts is a generic task occurring in a very wide range of industrial sectors (e.g. automotive, aerospace, process and electrical industries). In most environments there is a strong economic motivation to decentralise training, especially recurrent training and/or review of specific repair procedures before practising, which would make Computer-Based Training (CBT) an ideal solution.

The considered range of applications share a number of features which are particularly demanding, so that current off-the-shelf authoring systems for CBTs are basically inadequate for developing most applications:

to distribute training to a territorially sparse organisation. This implies to have the application on the cheapest and most diffused hardware.

To host the CBT application on a portable system, so as to make it consultable when doing the job.

The user interface should rely on high quality graphics and it should not require the user a cognitive effort to recognise the objects to manipulate.

To have concise and to the point explanations in such a way as to maximise the impact on the user.

To adapt training to a wide range of users, with different cultural background, language, capability, skill and professional experience.

The difficulties of matching all the mentioned requirements explain why the conventional CBTs, based on multimedia authoring systems available on the market place (e.g. Authorware, TenCORE, IconAuthor) had a limited penetration up to now in this sector where they could have large impact.

In the last decade a novel technology for CBT has been emerging, Intelligent Training Systems (ITSs), which couples domain and tutoring knowledge bases to sophisticated techniques for session planning [1], dialogue management and explanation production [3].

The ESPRIT project ASSIST EP-22935 (Computer-Based Assistance to Maintenance Tasks) integrated the CISE background tools (Intelligent Training Systems -ITSs), the Equipment Emulation infrastructure provided by VEGA (an SME based in Darmstadt active in the simulation and training markets) and off-the-shelf tools for VR into a coherent Toolset, and now is testing them for two pilot applications of large impact: training to maintenance of electrical equipment and training to aircraft maintenance.

During the first six months of the project the training needs analysis and the user requirements definition for both pilot applications have been carried out in parallel with the development of application prototypes based on the partner's background development software. The early

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fast prototyping of the two pilot applications had a significant impact to highlight and to finalize the user requirements.

This paper presents the results of the activities carried out jointly by CISE (now ENEL SpA) and AEM SpA, the electrical and gas utility of Milan, for the definition of the user requirements and the development and evaluation of a prototype application concerning training of maintenance personnel of low voltage and medium voltage electrical equipment.

TRAINING NEEDS ANALYSIS

The training needs analysis defined preliminary requirements of a software support to training. Within ASSIST, this activity was carried out according to a methodological approach that CISE defined throughout the experience gained during the development a of a number of training applications and prototypes [2]. This methodology addresses the specification of the fundamental elements of a training application such as the training scope, the trainee profiles, the detailed course program, the training strategies and methods.

The CISE methodology guides the software engineer to define the above elements in a format that can be directly implemented using the CISE software development platform. The advantage of both the approach and the toolset is that the activity directly flows into an application prototype for the demonstration of training scenarios that can be evaluated by the end-users and eventually mend the initial requirements. This cycling approach might bring additional requirements not already satisfied by the CISE software platform but that usually require only slight extensions.
Section 2.1 of this chapter presents the current training practice within AEM SpA and it also highlights the limits of the current course organisation. Section 2.2 gives a short overview of the scope of training and the different trainee profiles.

Current Training Practice

AEM SpA has three training courses for technicians: New Employee Training, Recurrent Training, and Refresher Training. All the three types of training courses emphasise practical aspects of the job instead of providing a deep knowledge of equipment functioning. Workers must memorise maintenance procedures, and they must know the physical structure of equipment and generic information like the scope and the high level functionality. The aim is to provide workers with the minimum knowledge required to operate the equipment properly and safely.

New Employee Training courses are organised every 3-4 months in order to form a significant group of new employees. Workers are first introduced to any kind of electric equipment, the related operative methods, and the generic safety criteria to be applied during job execution. After this theoretical classroom lecture workers have to follow practical training on real equipment. Practical training is carried out either on a piece of equipment of a real installation that has been disconnected from the network for training purpose or, when possible, the equipment is moved to the classroom.

Recurrent Training courses are organised on explicit request of the Sector Responsible when installation errors / accidents occur frequently on a specific equipment. In this particular situation an ad-hoc training course is organised focusing only on a specific equipment and on the related operative tasks and safety criteria. Refresh Training courses are organised for all workers any time a new type of equipment is introduced or when a revision of the operative procedures is introduced.

Current practical training has the drawback that it is too far from the real job situation because no electrical simulation of the equipment is used. Trainees do not feel the same pressure then during real job execution. They are too confident because the equipment is disconnected from the network. In this training scenario they know that no electric risk is present and that they can not incur equipment or network damage through errors. These conditions clearly alter trainee attention during the training exercise.

On-the-job training is needed after classroom training because AEM SpA is conscious that the current training programme does not completely match the work requirements. Thus, after classroom training a new employee stands beside an expert operator for a few months before being considered self-sufficient on the job.

Another problem with the current training courses is that workers' motivation is very poor, and most of them feel they already know everything about the training subject. This kind of situation happens because some of them already started training on-the-job before being trained in classroom, while the organisation is waiting for the next training course to be arranged.
No evaluation method is used to assure a minimum standard of knowledge and skills as required by recent European and National Laws i.e. n.626/94. A training tool that can adequately assess skill performance is desirable in order to guarantee a minimum level of qualification for all workers. Qualification need is also felt as a problem for jobs on contract. A training tool that offers this kind of functionality can be also used for getting a global assessment of the external worker skills.

Training Scope and Trainee Profiles

Training shall focus on electrical equipment knowledge, the related maintenance and installation procedure, safety procedures and the generic safety criteria to be applied during task execution. The AEM SpA pilot application shall provide training about Low Voltage (LV) and

Medium Voltage (MV) equipment, in particular it shall focus on the following electrical equipment and related installation and maintenance tasks:

three-phase metering units (LV): AEM SpA have 450 customers for the MV network, and for LV network have 40.200 customers with a three-phase metering unit installation and 410.000 customers with a single-phase metering unit installation. The AEM SpA pilot application will restrict to consider the three-phase metering unit.

distribution substations (MV): AEM SpA have about 2400 installations of distribution substations to be maintained into operation. These are classified within three categories: substations with plants in protected panels; substations with open plants; prefabricated substations for temporary installations. The AEM SpA pilot application will restrict to consider only substations with plants in protected panels.

The target trainee population is the approximately 500 AEM SpA maintenance workers. They vary in educational background, from primary school only (generally these are older and experienced operators) to secondary school. Some are university-trained engineers (these are generally younger, less experienced in the field, and more likely to be in supervisory positions). Job experience varies from new employee to many years work experience. Currently, AEM SpA has 3 categories of operative workers to be trained:

Coordinators: they execute manoeuvres on MV equipment in order to put a plant in a safe condition and are responsible for safety during work.

Supervisors: they execute manoeuvres on LV equipment in order to put equipment on safe condition and are responsible for safety during work. They also execute manoeuvres on MV equipment in order to put a plant on safe condition according to prescription received by the Coordinator.

Operators: they execute maintenance / installation tasks on LV/MV equipment. They are also responsible to put LV equipment such as metering units on safe conditions during task execution.

TRAINING REQUIREMENTS AND APPLICATION PROTOTYPE

In order to define the user requirements, the prototype was demonstrated to representatives of the end-users to consolidate the user requirements document. The AEM SpA application prototype is an almost functionally complete application that copes with a single electrical equipment: the three-phase metering unit. The developed prototype which copes with training on the three-phase metering unit for lecturing, tests and equipment manipulation exercises runs on standard PCs and laptops based on Windows 3.1 or Windows95.

The AEM SpA application prototype provides different modes of interaction in order to satisfy the need of all the three types of training currently coped with by the organisation (i.e. New Employee Training, Recurrent Training & Refresh Training).

For new employee training it guarantees that trainees achieve a good level of knowledge and skill on the whole course programme. For recurrent & refresher training the prototype provides a more flexible environment where trainees can ask to get training on a particular equipment and maintenance task.

Due to the large spectrum of users with a different background and duties, instruction is individualised to the real learning needs and preferences of the trainee. In order to provide individualised instruction the AEM SpA prototype maintains a data base of information about the trainee characteristics, course program and current achievements, and the training history as a log of errors and asked questions (e.g. what to do next, what about <component>). A training session is planned according to the data items recorded in the Student Model data base.

The application prototype provides two different kinds of instructional support: a guided-training and a self-training to satisfy the requirements of both new employee training and recurrent / refresh training.

In guided-training new employees receives instruction according to the course program defined by the training supervisor. The aim is to guide the trainee from an initial state of knowledge about the equipment and maintenance tasks to the target level of knowledge required for the role to be held inside the company. This is managed in a transparent way by the training system which selects the next training objective to cope within a training session and automatically plan a sequence of instructional units suitable to achieve the objective. The application prototype monitors the trainee performance in order to intervene for corrective explanations, for remedial lectures or for re-planning the session in case of trainee learning impasse.

In self-training already experienced employees receives instruction according to job emerging needs and time scheduling. The trainee sets his own training session plan and the training application executes it, while monitoring the trainee performance and providing explanations either in case of errors or on explicit trainee help requests.

During the prototype evaluation sessions, the AEM SpA instructors and training managers highlighted the need to provide two different training modes in such a way to clearly distinguish between training phases: a learning and practising phase, and an assessment phase. In order to meet this additional requirement the final AEM SpA pilot application will support two different training modes the tutor mode and the assessment mode.

Tutorial sessions shall have a duration established by the training supervisor who estimates the average time required to learn a topic. In tutor mode of interaction the application will plan a session with the goal to help the

individual trainee to learn everything about a training topic. During practical exercises the application will monitor the trainee performance in order to immediately intervene with corrective explanations, remedial lectures or for re-planning the session in case of trainee learning impasse. Performance monitoring will be only used to provide effective support to learning, because a real assessment of the acquired trainee performance will be done only during the assessment mode of interaction.

In the assessment mode the application shall plan a training session with the goal to evaluate the trainee knowledge and skills in order to check whether the training objective has to be considered totally or at least partially achieved. A number of iterations between tutorial and assessment sessions might be required when the training objective is not totally achieved.

Concerning training about procedures, the AEM SpA pilot application will focus on the operative methods to be used for putting equipment on safe conditions. Manual skills such as to prepare a conductor termination should not be the subject of training of the AEM SpA pilot application. Manual skills will be better learnt by direct physical manipulation. Both 2-D and 3-D modelling will be used for equipment emulation, soft VR will be fundamental for training those tasks that require an environment perception e.g. maintenance inside distribution substations.

In order to reduce software development costs, a realistic 2-D emulation will be preferred for those tasks that require to operate just a single equipment, e.g. metering unit maintenance. The target platform for the final pilot application will be a standard PC Windows NT. A consumer market graphic board will be necessary to support the real-time VR interface.

The AEM SpA application prototype already provides the following training methods in compliance with but complementing the methods currently used during classroom training:

Lecture: based on the presentation of the courseware, e.g. text and graphics. The trainee is allowed to freely navigate in the training material learning the different aspects of the subject matter in order he prefers. However, a lecture is different from usual hypertext with the respect to the way of limiting the navigation links which are accessible to the user. A trainee is allowed to access only those links that are useful for his learning progress, by considering individual training objectives and current achievements.

Procedure Demonstration: a demonstration of the procedure execution is given to show how to execute a task. This is complemented by explanation of the specific steps and any explanation of step execution is graphically animated. Equipment emulation is used in order to justify the correct way of operating according to both the procedure and the general safety criteria. In the final AEM SpA pilot application vocal explanations will be preferred to textual descriptions in such a way as to prevent trainee boredom.

Procedure Execution: the trainee is asked to execute the procedure in a virtual environment (see figure 1 below). The training system monitors the procedure execution and it makes a global assessment of the trainee performance taking into consideration interaction events such as errors, help requests (e.g. what to do next) and questioning about the equipment. In case of error detection the training system reacts in a different way depending on the event gravity and on the implemented training strategy. For serious errors that cause accidents or equipment damaging the application prototype always intervenes immediately by graphically showing the effects of the error on the operator and/or the equipment and plant. For less important errors the prototype either intervenes immediately (e.g. during New Employee Training) by noting the error and suggesting the correct way of operation or it records the error event and mentions it at the end of the exercise during the exercise debriefing (i.e. during Recurrent and Refresher Training).

The application prototype does not give any graphical feedback in case of contact events between the operator and live components, but the complete pilot application shall be able to animate the emulated environment by showing a blaze. Vocal messages and sound shall be used both in case of accidental contact events and wrong operations.

Tests: the user knowledge about the electrical equipment is assessed by means of multiple choice tests. Weights are associated to the different wrong answers the trainee can choose depending on the gravity of the underling error. A global assessment of the trainee knowledge is done at the end of a test basing on all the selected answers. The assessment identifies the trainee lacks in a specific type of knowledge associated to a topic in such a way to direct corrective actions just on the identified lacks.

In the application prototype a number of facilities to support the training supervisor are also available: to define and characterise the users of the system, to create and initialise trainee personal data inside the Student Model data base, and to set an individual training program. The training supervisor is also supported by facilities to assess the learning progress by inspecting the individual reports of the learning achievements of each trainee.
An additional requirement coming from the prototype evaluation sessions, and to be considered as an extension in the developement of the final pilot application, is the need to access a detailed group report on the types of problems the trainees experienced in such a way to better control the global process of learning on the whole population of trainees and tune it when required.

EVALUATION METHODOLOGY

The pilot application, concerning the three-phase metering unit, was delivered to AEM SpA on PC’s and 50 AEM

maintenance workers, with different job experiences, tested it.

Each operator did the training session providing at last an evaluation about this tool and its effective in order to learn.

The result of this first trainee's evaluation is positive because they enjoyed the tool but an evaluation of the learnt contents is premature because of the tools youth..

CONCLUSION

From the results of the training needs analysis it is evident that a computer-based support to training will be a valid solution to the problems highlighted by AEM SpA in their current training program. Computer-Based Training will supplement, not replace, the current training practice. In particular, maintenance tasks that requires a manual perception will go on to be trained by direct manipulation, and a brief classroom lecture will remain as starting introduction to both new employee an recurrent & refresh training courses.

Procedure Execution exercises where trainees can operate in a virtual environment, where dangerous effects of electrocution events on the humans are also simulated, and where equipment damaging and the related blackout effect on the electric network can be demonstrated, will be of great impact for training about safe operation and to increase safety awareness. Emotionalism during classroom operation has often a bad effect on workers performance.

The training application will allow operators to practice procedures and operations without being evaluated or judged by the instructor and by the other workers. Furthermore, thanks to the low cost of the target hardware platform required to run the pilot application workers can be easily trained at the working site directly, avoiding unnecessary relocation of people and equipment, and recurrent training can become a continous with the day-by-day job.

The need to qualify personnel will be well met by the AEM SpA pilot application that will ensure all operators perform according to a minimum required. Training supervisors will be supported by a tool that provides an objective evaluation of the worker's skills, i.e. by producing both individual and group reports of the learning progress, and it will allow supervisors to deliver to the workers at the end of training a qualification certificate.

This will have a twofold benefit for AEM SpA both for the legal implications in case of accidents and for the training

costs reduction (on-the-job training can be significantly reduced because personnel will be properly prepared). Furthermore, training will benefit from the standardisation of the pedagogic approach used, avoiding differences due to the individual attitudes of the instructors about knowledge and skill transfer.

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