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Abstract

Management flight simulators provide a “microworld” in which users control an organization in a realistic environment without the need to disturb the real system. This paper presents a web-based intelligent virtual learning environment to enhance the education of engineering management students in quality management and statistical process control techniques. The paper introduces the structure and methodology for building this online learning environment. The simulated environment is based on an innovative approach which incorporates a Fuzzy Adaptive Resonance Theory Neural Network to enable students to obtain the best response by automatically identifying out of control conditions.

Keywords

methodology, for, integrating, artificial, intelligence, into, quality, management, teaching, environment

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ABSTRACT

Management flight simulators provide a “microworld” in which users control an organization in a realistic environment without the need to disturb the real system. This paper presents a web-based intelligent virtual learning environment to enhance the education of engineering management students in quality management and statistical process control techniques. The paper introduces the structure and methodology for building this online learning environment. The simulated environment is based on an innovative approach which incorporates a Fuzzy Adaptive Resonance Theory Neural Network to enable students to obtain the best response by automatically identifying out of control conditions.

Keywords: *intelligent learning environment, virtual factory, SPC, ART*

I. INTRODUCTION

In recent years, emphasis on continuous improvement to maintain competitive advantage has focused the attention of academics and professionals on the need to teach engineering and management students the skills and understanding necessary to tackle and solve challenging multidisciplinary problems that call for critical judgment and creativity (Acosta, 2000, Veith et al., 1998). The need for quality engineers to possess balanced management skills, knowledge of engineering techniques and a statistical mindset is driven by the dynamics of the 21st century industrial environment. It is therefore important that engineering management education in statistics develops beyond theoretical teaching and tutorials based on simple examples, to a methodological approach based on realistic scenarios.

Simulation can help with the understanding of techniques taught in the management courses. Various tutoring systems using simulation have been designed to assist tutors in different disciplines to fulfil the needs of engineering management teaching. However an intensive expert knowledge and a considerable amount of time is required for developers to construct a curricula simulation system. In addition, simulations of industrial processes are based on estimates and statistical hypotheses which represent the real process. This paper introduces a web-based intelligent simulation environment based on artificial intelligence techniques in order to overcome several limitations of traditional engineering management education.

II. SIMULATIONS IN MANAGEMENT EDUCATIONS

Simulation has been used for a long time as a teaching aid. Seila (1995) suggests that simulation is an alternative realization that approximates to the system, and in all cases the purpose of the simulation is to analyze and understand the system’s behaviour under various alternative actions or decisions. Simulation has proven to be an important tool in the teaching, design, development and analysis of manufacturing systems and other environments. One of the underlying advantages of simulation techniques is their capability to model variation. Management games are well-established simulation techniques for improving the understanding and appreciation of realistic problems. Such systems are similar to flight simulators, which are physical devices that recreate the response of an aircraft to various actions the pilot might take, and therefore allow the pilot to learn how to control the aircraft. Flight Simulators (Sterman, 1992) for management where students “fly” a particular aspect of an enterprise are particularly rewarding. However, the construction of a typical simulation model requires intensive expert knowledge of the specific system. Simulation modellers often find that time, cost and limited domain knowledge restrict the development of a realistic system.

The term Intelligent Tutoring System (ITS) has been popularly used to describe a system with the ability to intelligently evaluate students' performance then assist throughout their learning process. Since the first ITS was built in the 1970s, there have been several applications which have been developed to fulfil various pedagogical purposes. SOPHIE (Brown et al., 1974) is one of the earliest ITS ever built for monitoring students debugging electronic circuits. It evaluates the student's strategy and critiques it according to its own built-in problem solving strategy which is based on the functional specifications of electrical circuits. GUIDON (Clancey, 1982) was designed to guide medical students attempting to diagnose a case of bacteraemia or meningitis. The system uses empirical information to teach students within a problem domain. In the industrial context, very few ITS have been developed (Frasson and Aimeur, 1998). Generally they have been built for teaching mathematics, trouble shooting detection and simple operational training purposes. Reis and Paladini (Reis et al., 2005) developed an artificial learning environment STCEQ (*Sistema Tutorial Inteligente para Controle Estatı´stico da Qualidade – Intelligent Tutoring System for Statistical Quality Control*) to teach industrial quality improvement techniques. They use an expert and tutor model to determine specific action based on the students' answers to questions. The intelligence in the system is mainly used to diagnose students' response so that their weakness in relevant topics can be highlighted and discussed. Another system SAFARI (Frasson and Aimeur, 1998) is a project developed by several universities and organizations in Canada in order to facilitate the creation of tutoring systems to be used in professional formation and procedural knowledge teaching. The project provides an approach to build a generic ITS to allow the use of multiple learning strategies. However, a problem emerged when the project became hardware and software platform dependent due to the complexity of the project scope. Therefore network based solutions are preferable for learning, especially in the industrial management education context, where hardware and software for training purposes are limited. Furthermore, a learning environment with the ability to intelligently help students analyse statistical process control data has not been created. Therefore a methodology is presented in the next section to develop a web-based intelligent learning environment for teaching statistical process control techniques.

III. METHODOLOGY FOR THE DEVELOPMENT OF THE INTELLIGENT LEARNING ENVIRONMENT

In order to develop the methods for building an artificial intelligent learning environment which uses original data to represent the process scenarios, the work is separated into two stages. The first stage is to build a web-based virtual factory using discrete event simulation so that the students can explore quality problems through controlling the virtual factory. VF will be used as the short name for this stage. The students' task at this stage is split into two weeks. We call these two sub stages Virtual Factory 1 (VF1) and Virtual Factory 2 (VF2). To complete these stages, students must choose and practice appropriate statistical quality control techniques. The second stage is to design and develop a new artificial intelligence (AI) approach based on the virtual factory to investigate problems from real-life processes so that students are able to discover the optimized process input variables by reducing the variation on the output. Virtual Environment (VE) will be used to represent this stage. The AI modules in the system also deploy several advanced SPC techniques which will enhance the students' statistical knowledge. The underlying SPC techniques and the stages in the system are illustrated in Table 1. Beside the SPC techniques listed in the table, activity based costing (ABC) and average throughput of products is also included in the environment, so that the students can develop an appreciation of how quality strategies affect the productivity and cost of a factory's output.

The web-based intelligent simulation environment (WISE) is not only a simple management game for

Table 1 Various SPC techniques applied to different virtual learning environment stages

SPC Techniques	**Virtual Environment Stages**
Control charting	VF1 & VF2
Control chart patterns	VE
Process Capability Analysis	VF1 & VF2
Design of experiments	VF2
Response Surface methodology	VF2
Specification limits	VF2
Correlation and Regression	VE
Distributions	VE

students to compete with other teams. It also explores the students' potential skills and underlying knowledge to manage the simulated organization into an optimized state. It provides a centralized platform for students to apply a mixture of statistical process control techniques in order to achieve the best possible improvement. WISE involves the following pedagogical targets in order to suit the needs of 21st century engineering management education:

1. *Analytical skills:* require the students to define the problems in the process and establish criteria that bound the potential solutions to solve the problems.
2. *Synthesizing skills:* develop the students' ability to evaluate alternatives against established criteria and decide on the best solutions, then verify if the solutions satisfy the system requirement.
3. *Communication skills:* through collaborative Internet-based discussions, improve the ability to communicate ideas with other team members during problem solving and decision making phases, as well as acquire knowledge through team members.
4. *Management skills:* develop the ability to manage time, be able to set goals and establish strategies.
5. *Leadership skills:* practice the ability to manage relationships with other team members and develop decision making skills.
6. *Competition awareness:* enhance the responsibility among competitors, be aware of using the

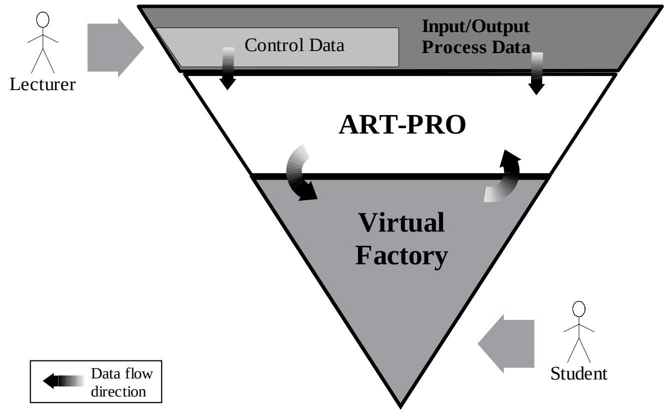

Figure 1 WISE architecture

shortest time to reach the best improvement target, therefore to achieve profit maximization and cost saving.

The architecture of WISE is illustrated in Figure 1. It is composed of three modules: the Data management module, the intelligent process optimization module and the virtual factory module. Students use the virtual factory as an interface to investigate quality problems and solve them using statistical process control methods. Lecturers can configure the learning environment by putting the control data and process data into the intelligent process optimization module (Adaptive Resonance Theory-based Pattern Reconciliation Optimizer (ART-PRO)). After learning the common SPC techniques the students are asked to move on to the next stage using their own data generated by the virtual factory or a real factory to investigate any further improvement or optimization. The ART-PRO module is designed to autonomously learn and analyse the process data, therefore decisions can be made upon the neural network analysis and reconciliation process. Two arrows on the diagram between ART-PRO and the virtual factory indicate the directions of process data flow being fed into the ART-PRO from the virtual factory for learning and reconciliation, and analyzed patterns being sent to the virtual factory.

The methodologies used to develop the two stages are introduced as follows:

3.1 Stage 1: Development of a Discrete-Event Virtual Factory Simulator

This stage aims to develop an online virtual factory within which, students can explore quality problems by controlling the machines within the factory. Students can manage the factory for either a period of 2 weeks, or a length specified by lecturers, with the factory running in real time. The main objective is to reduce quality problems and continuously improve the quality over a substantial period of time. Techniques such as control charts, process capability, experimental design and response surface methodology and their underlying statistics are explored. The simulator has the capability to generate the cost of production, the average throughput of products and process capabilities so that students can develop an appreciation of how quality strategies affect the productivity and cost of a factory's output. Thus a systems approach to managing the quality of a factory is encouraged.

The developed simulator creates a problem-based learning approach with relevant academic underpinning. It provides the student with the experience of applying theory to the practice of operating a factory in real-time. Students are able to "live" with the problem, research and develop solutions over a significant time period. It has always been a problem to teach effectively over the interface between two disciplines. This stage addresses this problem and enhances the learning experience by providing a realistic scenario over an extended time frame.

The simulator is interactively controlled over the Internet. The infrastructure is based on the concepts developed by Wood and Kumar (1999).Students and lecturers gain access through their group name and password. Each student group has their individual view of the factory under their control. The simulator is initialised with the same conditions by the lecturer. Individual students then access factories to inspect machine status. Figure 2 illustrates the interactive interface from the virtual factory. The machines are controllable through buttons and option boxes. Machine output can be downloaded and plotted into control charts using statistical analysis software. The lecturer can intervene by creating specific one-off conditions, for example unexpected failures, and obtain an overview of all the groups performances. A detailed description of this stage can be found in (Chi et al., 2004).

3.2 Stage 2: Construction of Web-Based Intelligent Simulation Environment (WISE)

Two assumptions have been made prior to the development of the intelligent learning environment:

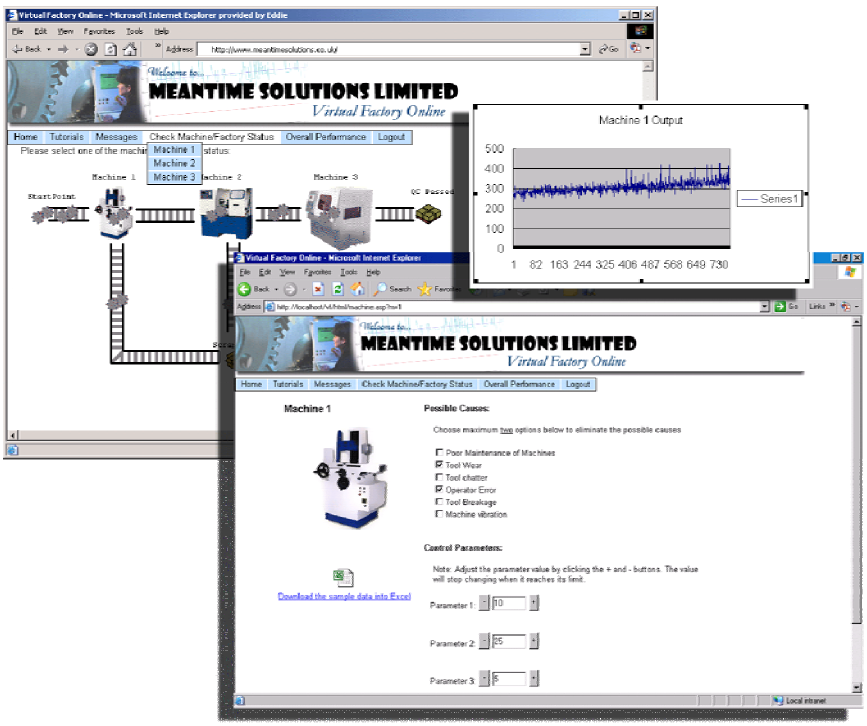

Figure 2 WISE Stage 1: Virtual Factory and Its Output

- Due to the complexity and variability of the process industry, the type of process will be limited to those with continuous input variables, which means the learning environment accepts variables with random input data.
- The factors which affect quality (referred to here as input data) and the quality characteristics (referred to here as output data) from the process should be easy to obtain and represent the majority of the process characteristics. Once the system possesses an adequately large database with good coverage of the characteristics, the artificial intelligent module is then able to compare the quality of new products entered into the system with the existing data (Hodge and Austin, 2004).

Stage 2 aims to develop an artificial intelligent virtual learning environment based on the virtual factory developed in Stage 1. It assumes that students have learned the designated fundamental SPC techniques through controlling the virtual factory, which at the stage is based on a hypothetical factory and data. The intelligent virtual learning environment will take the trainees one step further by using real data obtained from their own industrial environment. Regardless of the quality of the data, the simulation aims to encourage students and trainees to improve their own real-life process and to reduce variability. This will result in the real life process being optimized without performing experimentation on the actual system.

The central focus of stage 2 is an artificial intelligent architecture which uses artificial neural network (ANN) techniques, in particular, a Fuzzy Adaptive Resonance Theory (Fuzzy ART) (Carpenter et al., 1991) namely, Adaptive Resonance Theory-based Pattern Reconciliation Optimizer (ART-PRO). The architecture incorporates novelty detection techniques to identify abnormal patterns from the process data and reconstruct the process scenario model by learning the patterns represented in the data. The functionality of ART-PRO is to accept any process data either from an actual industrial scenario or from the simulation data obtained by the students. It then autonomously classifies the patterns from the given dataset for preparation for further improvement. At this stage, the students are given a chance to enter the input and output variable data for WISE to analyse the data. These input factors and quality characteristic output data can be obtained from the real process or downloaded from the virtual factory.

The main objective of ART-PRO is to take the students one level beyond the previous stage by reviewing the past process control activities. By framing dissimilar patterns into time-series windows, the process output can be intelligently analysed not only by the out-of-control rules specified in the text book, but also by demonstrating any potential outliers. Students identify and differentiate special or common cause variation exhibited in the windows. Based on their decisions, the students have the opportunity to control the output into a desirable outcome. The system will then match the possible input using patterns learned by the ART neural network. Therefore a backward operation is performed. In this way the students can gain an appreciation of how previous input variables should be controlled and therefore the process can be understood. It can then be improved and optimized even further. Restrictions must also be applied to such optimization as some processes can only be improved up to a certain level.

IV. Benefit of Using WISE for Management Statistical Education

People learn knowledge in very different ways. Some learn best through hands-on practice, many others by solving problems with a group of colleagues and some through reading technical manuals or self-study. Level of experience is also different when training is performed in the industrial context. Less experienced people naturally need more attention than their senior colleagues. Training must be personalized to each individual with specific learning styles and backgrounds. The learning environment described in this paper integrates artificial intelligence and online activities and so provides an ideal solution to various learning groups with different backgrounds.

Neave (2002) states that the effectiveness of both traditional classroom teaching and the use of interactive computer systems to teach management theories appear limited. The difference in most successful companies is that learning is generally enhanced with supervised hands-on work on the shop floor. Major education and training in managing process improvement projects is needed at all levels in most companies, from chart completion skills for operators, right through to basic conceptual knowledge about SPC at managerial levels. Therefore intelligent learning environments that demonstrate classroom taught SPC theories, develop a methodological approach and apply real manufacturing scenarios will bring the factory into the classroom. By developing a new approach to teaching continuous improvement techniques through the introduction of a web-based virtual learning environment, managers can concentrate on important issues whilst obtaining quality improvement skills at any time, anywhere.

V. Conclusions

The overall structure of WISE provides a platform for engineering management students to systematically master fundamental statistical process control techniques in a heuristic and hybrid virtual environment. Through web-based online collaboration, higher efficiency and better understanding can be achieved via group work and communication. The students therefore become active rather than passive learners. The first stage of the system has been tested in a university in the UK (Chi et al., 2004). Results have shown that students were positively inspired by this way of learning.

In real life even the most experienced and knowledgeable decision makers sometimes filter their information through non-systematic mental models, construing symptoms as causes and reacting in ways that often make problems worse rather than better. This has been found through the experimental design phase deployed during the VF2 stage of the project using the WISE system. Students could lead the factory into tremendous loss even if they are using a standard way to perform the experiments. While increasing access to more information may be a step in the direction of enhanced learning, more information is not always better. Therefore backward engineering by using ART-PRO is very helpful for students to review the learning process in the right time, and heuristically examine the past activities. In this way students enhance their knowledge as well as improve their experience.

Furthermore, realistic data can be applied to the WISE system so that students can gain an appreciation of how a real system reacts by adjusting the output to control the input variables reversely in order to obtain an improved process. Although this “realistic” simulator presents a few measurable parameters with less mechanistic detail, it exposes students to broader interactions between computer systems and manufacturing equipment, and immerses them in a motivating and challenging realistic environment. Due to the variety of the industrial processes, it is time and cost consuming to build a simulation model to faithfully reflect the behaviour of such a process. With the help of artificial intelligence techniques, the simulation model is constructed based on the real process data without previous knowledge of the process. Students and trainees then can obtain machine responses which respond exactly as in real life.

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