1-1-2006

An interactive learning environment for teaching statistics

Trevor Spedding

University of Wollongong, spedding@uow.edu.au

Xuesong Chi

University of Wollongong, xc569@uow.edu.au

Abstract

This paper outlines the development and use of a web based virtual factory simulator for teaching industrial statistics and process improvement techniques. Students can manage the factory for either a period of one month, or the 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. This immersive simulation 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 and research and develop solutions over a significant time period.

Keywords

interactive, learning, environment, for, teaching, statistics

Disciplines

Business | Social and Behavioral Sciences

Publication Details

Spedding, T. A. & Chi, X. (2006). An interactive learning environment for teaching statistics. In E. Pearson & P. Bohman (Eds.), ED-MEDIA 2006 (pp. 2429-2434). USA: Association for the Advancement of Computing In Education (AACE).

An Interactive Learning Environment for Teaching Statistics

Trevor Spedding and Xuesong Chi, University of Wollongong, Australia

This paper outlines the development and use of a web based virtual factory simulator for teaching industrial statistics and process improvement techniques. Students can manage the factory for either a period of one month, or the 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. This immersive simulation 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 and research and develop solutions over a significant time period.

INTRODUCTION

Management games are well-established techniques for improving the understanding and appreciation of realistic problems. Flight Simulators (Sterman 1992) where students "fly" a particular aspect of an enterprise are particularly rewarding. A web-based virtual factory and simulator platform for teaching industrial statistics and process improvement techniques has been developed. It provides students with experience of a "flight simulator" which allows them to practice effective decision-making and demonstrates the practical application of industrial statistics in a realistic environment.

The web based virtual factory was developed so that students can explore quality problems by controlling the machines within the factory. Students can manage the factory for either a period of one month, or the 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 calculates and outputs 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. Teaching statistics to engineers is often a challenge in terms of motivation, understanding and developing an appreciation of the significance of the application of statistics in solving important engineering problems (Spedding 2001). This project addresses these problems and enhances the learning experience by providing a realistic scenario over an extended time frame. One of the main advantages of using this approach is that the students are able to develop a methodology for quality improvement rather than just an appreciation of the individual tools.

The infrastructure of the system is based on the concepts developed by Wood and Kumar (1999). The simulator is interactively controlled over the Internet. 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 by the lecturer so that each group has an identical starting point. Individual students then access factories to inspect machine status. The lecturer can intervene by creating specific one-off conditions, for example unexpected failures, and obtain an overview of all the groups performances.

The developed simulator illustrates the need to follow statistical methodologies, and helps students recognize the crucial role played by these methodologies in the analysis of production systems. In the current economic climate, it is essential that organisations and manufacturers maintain a competitive advantage. It is through the teaching and understanding of statistics to the next generation of engineers that such advantages can be sustained.

THE VIRTUAL FACTORY

The virtual factory platform consists of three machines as illustrated in Figure 1, representing three processes of a production line to manufacture components for the automotive industry. All components that do not meet the quality criteria (i.e. out of product specification) will be wasted, due to the nature of the process. In the early stages the factory is assumed to be running all the time without affecting the lead time and inventory. Before the factory starts, the system generates a certain amount of product data for students to download and analyse. As is the nature of web-based simulation, the simulator will stay static if it is not activated by any event. As the factory restarts, every time a group of students log in, the simulator will start running and record data into the database. The data will accumulate and be collected into the spreadsheets by downloading a server-generated Excel file. When the students log into the system, the data is calculated, and they will view the factory running continuously at the server side.

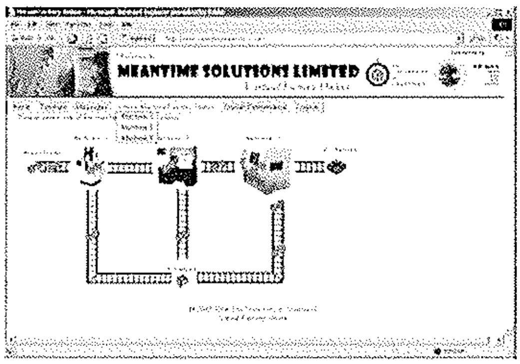

Figure 1: The Virtual Factory Layout

The students' task, as the newly appointed quality action team, is to control the system and improve quality within the factory making sure that there are minimal defects while also maximising the financial returns. Students need to log into the system regularly to check the status of the machines by downloading the critical quality dimensions (one for each machine) into a database. The simulation is designed so that the performance as well as financial returns deteriorate if the students try to 'guess' the parameter values.

The developed simulator platform comprises two main modules (see Figure 2): a student module and an administrator module. The simulator tool contains interactive pages and links which teach the underlying statistics and solutions. It is configured by the lecturer/administrator so that data streaming from the system can be downloaded and analysed off-line, using software of the user's choice or online using tools such as control charts which can be integrated into the system to streamline the analysis.

A dedicated messaging system works inside the simulator. Lecturers/Administrators are able to send individual or global messages to the students. The students can then reply or initiate messages to the lecturers. This facility enables more flexibility of communication between lecturers and students. For example, the lecturer can set up a malfunction on a certain machine, and then inform the groups that an event has happened. The students, as the quality control action team of the factory, need to provide timely dynamic decisions in order to make a profit.

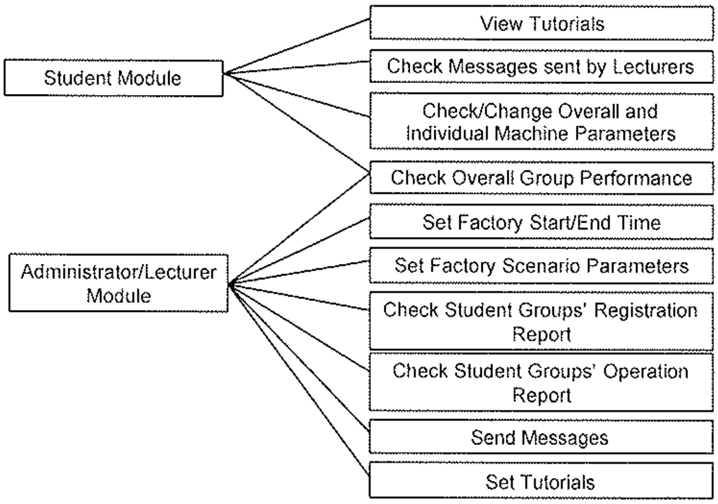

Figure 2: Structure of the Virtual Factory System

Through their own group name and password, the students are able to access their own factory. The simulation engine handles individual scenarios for each group. Therefore they operate the factory without affecting other groups. The students can also access the other groups' overall performance to see their ranking among all the groups.

The students can access the factory floor, choose certain machines, change the parameters and download product output data, read messages set by the lecturers, read tutorials and access the overall groups' performance ranking list, as illustrated in Figure 3. Lecturers or administrators have full control of the online simulator. They can set up the initial scenario, develop their own story or using the ready-made templates, set the factory start and finish times and send messages to the student groups. They are also able to view the student registration information, the groups overall performance and the operations carried out by each group.

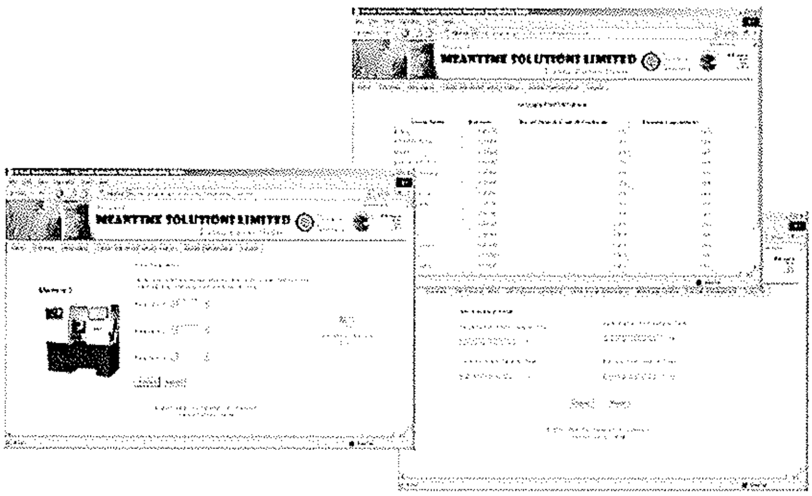

Figure 3: Screenshots from the Virtual Factory

The web-based virtual factory is based on discrete-event simulation theory (see for example Banks and Carson and Nelson 1996). The simulation engine employs a multiplicative congruential Gaussian random number generator based on based on the Box Muller algorithm (Box and Muller 1958) which generates the individual dimensions produced by the three machines. Linear trends and random numbers are added to the parameters produced by the random number generator to simulate special causes or variation such as trends and freaks. These special causes of variation are controlled (ie they can be turned on and off) by the radio buttons on each machine The three slide bars on each of the machines control the variance of the random number generator and so need to be adjusted to reduce variation in the experimental design stage of the simulation exercise.

STATISTICS

The Quality Engineering course for which the virtual factory was originally designed is a traditional quality course starting with an introduction to statistics and a review of measures of location, spread and distribution, the normal distribution and the central limit theorem. Common and Special causes of variation and their link to management and worker action on the system are outlines. Statistical Process Control (SPC) and the concept of dynamic feedback on the system are discussed. SPC methodology first ensures the system is in control (ie the mean, standard deviation and distribution do not change with time) using a control chart. Once in control the process capability can then be determined. Finally the (common cause) variation of the system can be reduced through offline techniques such as Experimental Design and Response Surface Methodology. The methodology and sequence of these tools is stressed as some of the assumptions for analysis are based on the previous results, for example the process capability should not be calculated unless the control charts confirm that the process is in-control.

An important aspect of understanding how to use SPC techniques is to appreciate the dynamics of particular quality problem and how it evolves with time. This will help the student determine what techniques to apply at a specific point in time and how to interpret the results before moving on to the next part of the problem. The virtual factory develops an understanding of this problem by simulating the production and quality output of the factory over a period of time. In the example tested in the classroom the factory was run over a two week period, with break for weekends (at the request students). When the students logs onto the factory they are faced with a scenario which is dependent on the previous settings (by the student) of the factory.

The factory consists of three machines and each machine has several adjustable settings effecting the special and common cause variation produced by the machine. Each machine produces a part every fifteen minutes (real time) and a critical dimension (eg diameter) is recorded and appears on the screen The numbers can be downloaded to an excel file for analysis. The factory is initialized with a days history (100 readings of each machine). The first objective is to determine if the three machines are in control. This requires downloading the data from each machine into a spreadsheet and calculating the control charts. We originally contemplated drawing the control charts in the actual simulation program so the student could simply review the control chart patterns on-line. However we decided it would be more beneficial for the student to draw his or her own control chart in excel so that he or she could select the most appropriate subgroup and work through calculations to determine the control limits etc. The student should find that although data from all of the machines falls within the control limits, one of the machines has a trend of more than eight successive increasing points (given that the student selected an appropriate sub group size). The objective then is to get the machine under control. Originally the student was asked to bring the machine under control by adjusting its three slider settings. However an initial trial of students indicated that this was too much of a trial and error process, so in the current version of the factory the student is asked to leave the slider settings untouched and is directed to six radio buttons which represent the following causes: poor maintenance of machines, tool wear, tool chatter, operator error, tool breakage and machine vibration.

The student needs to distinguish between common and special causes and which type of special cause of variation would produce an increasing trend in the data points. By selecting the two appropriate radio buttons the output produced by the machine will be brought into control. This is a good example of using a knowledge of engineering to interpret statistical analysis. The engineer should know from the type of machine described in the scenario, for example, that a worn tool will produce an increase in diameter over time. This type of engineering knowledge applied to statistical analysis is fundamental in providing fast and accurate feedback to problem solving in an engineering environment. Given that the students have applied the appropriate methodology, at the end of the first week the three machines in the factory should be in control.

At the beginning of the second week the speed of the factory is enhanced to produce 20 parts per hour and the product specifications for the three machines are given so that the student can calculate process capability. It should then be found that although the process is in control one of the machines it is not capable of producing the parts to the given specifications. The prime objective of the second week is to reduce variation and hence improve the process capability of the process. This is done by performing a 2^3 factorial design. Each of the three control parameters of the machine is adjusted about 2 levels to produce a response in terms of the quality output of the product. The student adjusts the levels according to the experimental design so that the number of defective products is reduced.

The best groups are able to complete the analysis by performing response surface methodology. This involves expanding the 2^3 factorial design to a central composite design and performing a search to find the combination of setting which produce the lowest number of defective products. The stages of the methodology and example outputs of the date are illustrated in figure 4.

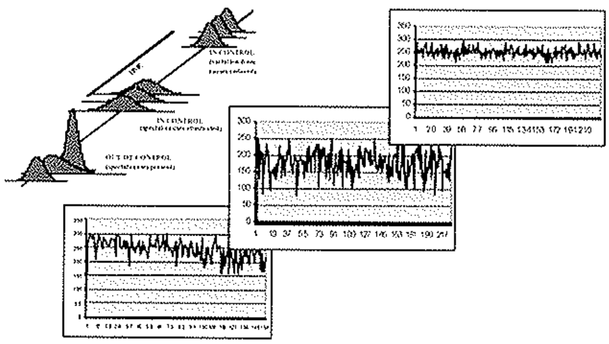

Figure 4 Stages of the Methodology and Example Output

DISCUSSION

The system has been tested and validated by Masters Students studying on a Quality Engineering course at the University of Greenwich, UK. The virtual factory was run as an assignment for two classes over a two year period. Students demonstrated significant interest and motivation in the virtual factory and particularly enjoyed the competitive nature of the simulation. The simulator provided very positive feedback, including recommendations by several part time students to use it as a training aid for their companies.

The system administrator set up a virtual "control" group account called the "Do Nothing Team" in order to give the students a system competitor and a reference point to assess their own factory's performance. The Do Nothing Team is in effect a dummy team carrying out no actions on the machines during the period of simulation. The Group Operation History function in the administrator module assists the lecturer to objectively assess students' written reports after operating the factory. By examining each group's login records and operational history, lecturers can identify any inconsistencies between the system and the written records.

Students hand in a comprehensive report detailing how they controlled and operated the factory during the two week period. Marks are given marks for overall performance and the final report. It was instructive to compare the activity log generated by the virtual factory with the actions outlined in the report. Because the students were operating in a competitive environment and were able to view each others performance some took short-cuts when applying quality theory. For example in the first year of testing, at least one group failed to complete an experimental design when they obtained zero defects from a certain combination of machine settings. Several other groups, who were in a strong position in the ranking table were reluctant to explore quality improvement techniques incase they compromised their competitive advantage. At first it was disappointing that the students abandoned sound statistical and quality practice but in reflection it was interesting to note that they were operating within competitive constraints similar to real life and thus exhibiting similar working characteristics. The factory was later revised so that it was not possible to determine the optimum settings of a machine until the experimental design was complete. The factory was also revised so that it continued to run for several days after the students had completed their analysis so that the long term effect of their decisions could be taken into account. On this occasion the student's reports reflected a more realistic description of the theory and practice of the exercise and less "gaming" took place.

CONCLUSIONS

A web based immersive simulator for teaching the application of statistics in an industrial environment has been discussed in this paper. The system has been tested and validated by Masters Students studying a Quality Engineering course. Students demonstrated a significant interest and motivation for such an online environment. The simulator provided very positive feedback, including recommendations by several part time students to use it as a training aid for their companies.

The web based immersive simulator will help teachers of engineers to illustrate the power of statistics in solving real engineering problems by providing a virtual simulation which is both physically and dynamically a realistic replication of the industrial environment. The virtual factory will offer students an opportunity to interact with a realistic scenario over an extended period. This is particularly important to both engineering students who sometimes find it difficult to appreciate the practical relevance of statistics, and statistics students who may find it difficult to appreciate the practical application of their discipline. The website will also be of use to industry as a training tool for quality improvement.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Royal Statistical Society Centre for Statistical Education, the Maths, Stats and OR Network, UK and the Medway School of Engineering, University of Greenwich, UK for jointly funding this project.

REFERENCES

Banks, J., Carson II, J S and Nelson, B. (2004). *Discrete-Event System Simulation.* 4th ed. Prentice Hall International, Inc.

Box, G. E. P. and Muller, M. E. (1958). A Note on the Generation of Random Normal Deviates. *Ann. Math. Stat.* 29, 610-611, 1958.

Spedding, ,T A. (2001). A Working Model of a Manufacturing Enterprise with Internet Control. *International Journal of Engineering Education* Vol 17 No 2 pp 197-206,

Sterman, J D. (1992). Teaching Takes Off: Flight Simulators for Management Education. *OR/MS Today* (October), 40-44..

Wood S C and Kumar, S. (1999) The Virtual Factory: Technology in Teaching Goes to a New level *Stanford University Research Report* November