

SPECIAL PROJECTS IN UNDERGRADUATE HUMAN FACTORS COURSES: EVALUATION OF POWER PLANT BOILER CONTROL INTERFACE

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A special project involving a campus utility plant HMI evaluation was offered to a group of undergraduate students enrolled in an introductory human factors class. Fifteen out of 55 students enrolled in the course volunteered for the special project. Specific subtasks were created in collaboration with the plant management and allocated to subgroups of students. These subtasks were scheduled to coincide with corresponding topics in the course. Evaluated by both the educational outcomes and the usefulness of the project deliverables to the power plant, the project clearly represents a beneficial situation to both students and instructors. The value of hands-on experience with task analysis, control room design, and HMI design to the students is undisputable. This case is also exemplary in terms of providing a service to the University community as a byproduct of the academic pursuits.

INTRODUCTION

Introductory human factors courses pose difficult choices for the instructor. By definition, most students have little prior exposure to the topic of human factors and the associated principles and methods. Explanation of these in lectures is often difficult, regardless of the instructor's best efforts to provide examples and real-world illustrations. On the other hand, many truly realistic examples are by nature too complex to clearly convey the concepts they are evoked to illustrate. Further, some examples from research literature are far removed from students' realm of experience. For example, how many psychology undergraduates can have a full appreciation of the challenges to pilots' decision-making in the highly automated glass-cockpits of airliners?

There often exist, however, opportunities to study real world human factors problems in a variety of applied settings on campuses, as well as in the community, that could be integrated in human factors courses to enhance the pedagogical outcomes of such courses. While these examples are just as complex as any other real-world system, their proximity and consequent accessibility to students provide valuable opportunities to illustrate the difficulties human factors professionals must frequently deal with as well as methods for overcoming them. Moreover, exposure to such complex systems while engaged in the structured environment of a college course provides a challenging atmosphere yet one in which the students will not become overwhelmed due to the support provided by instructors and teaching assistants (TAs). However, integrating large, time-consuming, applied projects with uncertain outcomes to often very overcrowded course schedules remains problematic.

This paper will describe integration of a steam plant human-machine interface (HMI) modernization effort into an introductory human factors course at the University of Illinois at Urbana-Champaign (UIUC). Given the respective constraints of both the course syllabus and enrollment on one hand, and the construction and installation of the new digital boiler control system at the power plant on the other, a special project with a number of carefully defined subtasks was offered to interested students who volunteered for the work.

INTRODUCTION TO HUMAN FACTORS AT UIUC

The introductory human factors course at UIUC is titled "Human Factors in Human-Machine Systems." It is a four credit hour course cross-listed by the Aviation (AVI), the Psychology (PSYCH), and the Industrial Engineering (IE) departments. In addition to lectures, the course involves up to seven laboratory exercises, comprising of typically single-subject, computerized experiments followed by a lab report assignment. Students are also required to complete a final project for the course, usually involving identification of a poor human factors design in the real world (e.g., a car dashboard or a cell phone display) and outlining a redesign in accordance with the human factors principles and guidelines covered in the course. The course text is Wickens, Gordon, and Liu (1998), "An introduction to human factors engineering."

Presently, this course emphasizes breadth over depth, with an explicit goal of providing the students with an appreciation of the diversity and multidisciplinary nature of human factors. This focus equips students to make informed choices for further, more narrowly focused, human factors courses as their educational careers progress. The course also presents the human factors principles rather matter-of-factly, with limited coverage of the underlying theories and research due to time limitations, and with a distinct orientation towards design. Another benefit of including a real world project in this course is the added depth, in a few areas, that the student will receive.

THE ABBOTT POWER PLANT

The Abbott Power Plant (APP) on the UIUC campus entered service in 1941. The plant has a peak capacity of 30 Megawatts and a total of six boilers. Three of these are dual fuel boilers, operating on either natural gas or fuel oil, and produce 325 PSI steam at 700 F at a rate of 175,000 lb/r. Two 150,000 lb/h boilers and a 200,000 lb/h boiler burn coal only and produce 875 PSI steam at 760 F. Electricity is generated by seven steam turbines, five 3000 kW low pressure variable extraction units, and two 7500 kW high pressure variable extraction turbines that can only be run off the coal boilers.

The main product of the plant is steam, which is used for a several purposes including heating campus buildings, cooking food in the dorms, heating water, and running air conditioning condensers as well as for a variety of research needs. Under campus there are 35 miles of pipe in over seven miles of tunnels to distribute the steam. Steam is also used to generate electricity. What electricity the plant does not supply to campus is purchased from Illinois Power.

The power plant is currently undergoing a major modernization project in order to build up its capacity to supply all of campus' needs and to reduce the reliance on Illinois Power during times of heavy demand. The old boiler controls, located at each boiler, and the series of master alarms in the main control room, will be replaced by digital control technology produced by Emerson Process Management. This technology will allow for the current controls located at each boiler and the old control room to be replaced by centrally located boiler control interfaces. However, each boiler will still retain a digital display/control panel nearby.

Eventually, the entire plant can be controlled from the control room, with little need for the operators to walk to individual boilers or turbines except in the cases of inspection or emergency. Compared to the old human-machine interfaces (HMI) in the plant (Figure 1), digital control and the DeltaV system (figure 2) represents a quantum leap in usability and operator safety and comfort. However, managing such a large amount of information on a single, 17-inch CRT screen may be difficult for a single technician or operator. Further, this change in controls systems can also be difficult for operators who are not used to using digital displays in power plant management.

A SPECIAL PROJECT AT THE ABBOTT PLANT

Research is not new to APP. Often, the equipment at APP is being examined in an experiment. Some of the ongoing research at APP include modeling atomic properties of first-wall materials, the Ion-surface InterAction eXperiment (IIAX; experiments and modeling on liquid metals), the Illinois Debris Experimental Applications Laboratory (IDEAL; Debris Mitigation), and Plasma Quest (Plasma Processing of Materials for Use in Medical Applications).

Though many campus units find research areas of interest at APP, none thus far have focused on HMI issues. Fortunately, the change in focus caused by large-scale renovation brought the potential human factors problems associated with the boiler control modernization to the attention of the plant manager, who consequently approached the faculty at the Aviation Human Factors Division (AHFD) at UIUC. Given the scale of the task and limited resources of the faculty, human factors evaluation of the new HMI appeared well-suited for a course project, with a fairly large number of students working on selected subtasks.

Organization and Management of the Project

The AVI/PSYCH 258/IE 240 course had 55 students during the fall semester of 2002. There were several factors to be considered before offering the Abbott project to a class of this size and at this level (i.e., introductory human factors course). First, it was clear that it would be impossible to provide access to the plant to such a large number of

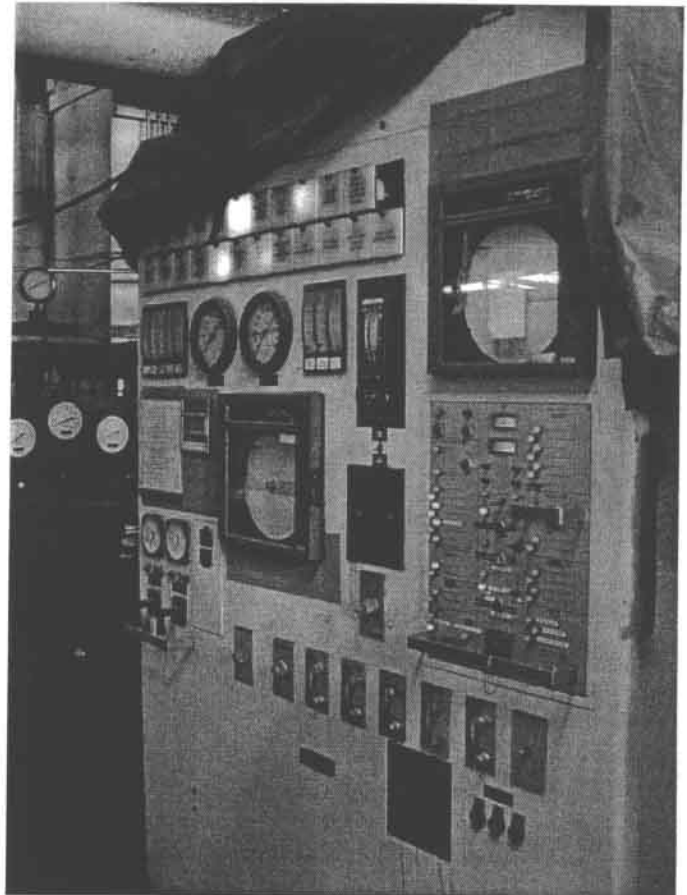


Figure 1: Old dual-fuel boiler control panel at the Abbott power plant. In addition to this panel, valves and controls are located in various locations around the boiler (visible in the background).

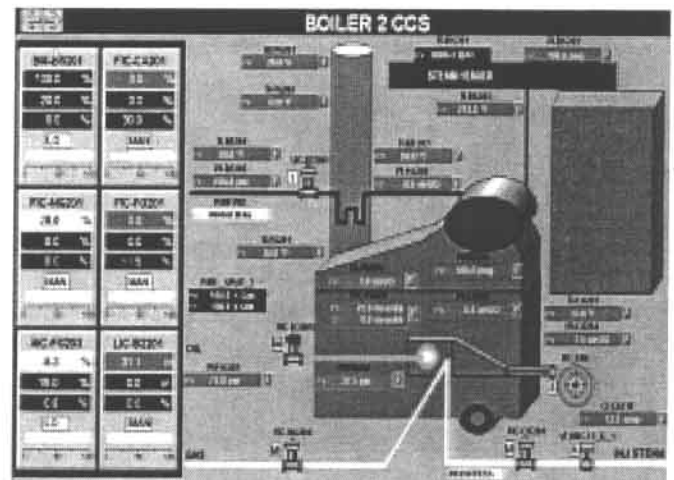


Figure 2. The new digital boiler control interface for the Abbott plant.

students—only one operator was available four days a week to speak with the students. Second, the envisioned project required a time commitment that went well beyond the regular class and lab times since students would have to interview the operators multiple times, observe plant operation over a course of weeks, and compile a comprehensive final project aside from any work required in class. Finally, due to the course instructor's and TAs' limited resources the students undertaking the project would need to be able to work with minimal supervision. Hence, the project was incorporated into the regular course as a special project, for which interested students could volunteer to participate. The only incentives offered to the students were an opportunity to work on a real-world application and a ready topic for their final projects. The objective of this arrangement was to attract only the best-motivated students for the project.

Out of the 55 students enrolled in the course 15 volunteered for the special project. An introductory tour of the power plant was arranged in collaboration with the plant management. The scope of the project was explained to the volunteering students and specific subtasks allocated to subgroups of students. These subtasks included:

- (1) Task analyses of selected power plant operator tasks
- (2) Human factors evaluation of the new boiler control interface
- (3) Review of human factors handbooks, guidelines, and literature for HMI design specifications
- (4) Design of the physical layout and dimensions of the plant control room
- (5) Design of a boiler control interface based on (1-3) above.

These subtasks were scheduled to coincide with corresponding topics during lecture and lab discussions. Further, the students in the special project group were exempted from regular lab assignments on the same topics. Coordination between the instructor, TAs, and students was accomplished through meetings with the entire group, with subgroups, and with individual students as well as frequent e-mail correspondence including all project participants.

RESULTS

Task Analyses

Tasks for which task analyses were to be performed were identified by the plant management. These included boiler startup and shutdown, manual operation for casualty control, normal monitoring, adjacent boiler startup and load balancing, emergency procedures for loss of steam load (turbine trip), loss of feedwater flow, loss of electrical power, and unknown trip, as well as maintenance and testing. This phase proved to be both very difficult and very educational. Task analysis can be very challenging undertaking for even experienced human factors professional, and the students discovered the complexities of both the operators tasks and the task analysis methods early on, in a way that could never have been conveyed through a classroom lecture. An additional complication was that very few of the plant operators were able to explain their tasks in a way that was understandable to a naïve student-analyst. Nevertheless, the results were useful,

and revealed several shortcomings in the procedures employed in the plant.

Interface Evaluation

This subtask was essentially a paper-and-pencil exercise of evaluating several screenshots of the new boiler interface against several human factors principles that were covered in a series of lectures at the same time. Although the limitations of such a static analysis must be acknowledged, several design issues were discovered for later analysis.

Review of Human Factors Literature

This subtask involved summarizing relevant guidelines from available literature for later redesign work. Specifically, guidelines for use of color and fonts on CRT displays, touch-screen design, and icon design were generated. In addition, the students modified Cardosi and Murphy's (1995) human factors checklist for the design and evaluation of air traffic control systems for use in the powerplant.

Control Room Design

Concurrent with lectures on anthropometry and workspace design, the student in this project prepared draft design for the new control room layout for the power plant. This work included determination of the appropriate dimensions of desks and chairs and the overall placement of displays and controls.

Redesign of the Boiler Control Interface

Finally, to "put it all together," the students prepared their suggestions for a redesign of the boiler control interface. These designs were generally very thoughtful, and with little extra effort could be turned into functional prototypes for a plant simulator for usability testing. This, however, must be deferred for another special project opportunity.

DISCUSSION

Success of this project must be evaluated on two parallel scales. The first criteria pertain to the educational outcomes in terms of meeting the course objectives. The most tangible evidence of a successful integration of a real-world project with a human factors course came from the students involved in it. All were very enthusiastic about their tasks, frequently exceeding the prescribed requirements, and clearly eager to apply the material covered in class.

The project participants also received very good grades for the course at the end of the semester. The mean score of the project participants was 87.8 versus 79.3 for the rest of the students. Out of a total of 18 As in the course, the project participants had 10. However, these educational outcomes are probably confounded by the self-selection of project participants. As was mentioned earlier, it is likely that only the best-motivated students volunteered for the project, and that they would have received high grades in any case. Nevertheless, many of the project participants enrolled in additional human factors courses in the subsequent semester, which could also be taken as a measure of the success of the project.

The second set of criteria relate to the usefulness of the project deliverables to the Abbott power plant. The task of evaluating the new, digital, control interface is of course huge and not something that could be accomplished in a single semester. However, our efforts paved way for future work in several important areas. First, the tasks analyses are presently being reviewed by plant operators and will be used for a basis of standard operating procedures and checklists for the plant. These revisions and further expansion to the final projects are being undertaken by upper-level undergraduate research assistants working on independent research in human factors. Further, the work done on HMI design yielded enough basic material for the design of an improved boiler control interface and development of a functional prototype for usability testing.

Finally, this project also established good working relationship between the Abbott management and operators, programmers at Emerson Processes Management, and the human factors faculty at UIUC, opening new opportunities for future collaboration. Consequently, Emerson Process Management has loaned two power plant simulators equipped with DeltaV to human factors researchers at UIUC as the next step in evaluating the DeltaV interface and creating an improved boiler control GUI.

CONCLUSION

This project clearly represents a valuable teaching tool as well as a benefit to the industries involved; the value of hands-on experience with task analysis, control room design, and HMI design to the students is undisputable. Not only did

such experience reinforce learning of the materials covered in the course, but also offered the students an important glimpse to the work of human factors professionals and the complexities of real-world problems they encounter.

It is yet premature to assess the benefits of the project to the power plant management and personnel. However, much important groundwork was accomplished during a single semester, offering a solid foundation for other similar projects in the future. Finally, this case is exemplary in terms of providing a service to the University community as a byproduct of the academic pursuits.

The success does involve a cost, however. Management of a project of this scale imposes significant demands on the supervising faculty member's time in addition to his or her teaching responsibilities and other research pursuits. In many cases it may be impossible for a faculty member to assume such workload. It is therefore imperative that integration of applied human factors work into regularly offered courses is rewarded and actively promoted also by the university administration.

REFERENCES

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