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Ecological Interface Design in Practice: A Design for Petrochemical Processing Operations

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Abstract

This paper describes the design of an ecological interface for an existing petrochemical process. We describe the iterative design process by example and identify the challenges of applying the Ecological Interface Design framework in industry using a user-centred design approach.

1 Introduction

Ecological Interface Design (EID) is a framework for designing graphical user interfaces (that is, ecological interfaces) for complex systems (Vicente & Rasmussen, 1992). Over the past decade, researchers have reported substantial progress in applying EID to a variety of work domains of increasing complexity (see Vicente, 2002). However, the literature lacks depth in two key areas. First, it offers few applications of the framework to real work domains. Second, it tends to focus on the design product rather than on the design process (cf. Reising & Sanderson, 2002). These two characteristics limit the usefulness of the EID literature for industry practitioners who might consider designing ecological interfaces for applied problems. The two objectives of the work discussed in this paper were: a) to extend the literature by applying EID to an existing industrial process, and b) to identify the challenges of applying EID in a user-centred design process in industry.

We designed a novel graphical user interface for an ethylene manufacturing process. EID formed the basis for an iterative design approach that incorporated several types of user feedback. Although EID does not contradict other user-centred design approaches, its emphasis on using work domain analysis to identify information requirements may reduce the attention that designers devote to acquiring user feedback in the design process. This has been compounded by the fact that there have been no expert users of the laboratory microworld simulations for which most ecological interfaces have been developed. Given that we were working in an industry setting with a population of domain experts as users, stakeholder acceptance of the designs was critical.

The target domain is a sub-process of an ethylene refining plant. The reactor converts acetylene in a hydrocarbon stream into ethylene by reacting acetylene and hydrogen in the presence of a catalyst. However, other hydrocarbons in the process stream will react with hydrogen as well, giving off heat and destabilizing the reactor. The operator must balance hydrogen consumption, reducing the acetylene concentration in the product stream to below 5 ppm and minimizing excess hydrogen. This is done by regulating the flow rate of the mixed hydrogen stream.

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2 Iterative Design Approach

We employed an iterative approach when developing the functional interface. At several stages, target users and other domain experts provided feedback that factored into subsequent revisions. In the following sections, we describe three iterations of the display and the user feedback solicited.

The results of a work domain analysis (Miller & Vicente, 1998) and two task-based analyses (Miller and Vicente, 1999; Jamieson, Reising, & Hajdukiewicz, 2001) formed the input to the design process. Information requirements derived from those analyses were compared, filtered and assimilated into a comprehensive list that drove the design process (see Jamieson et al, 2001). In reviewing this list, the critical role of hydrogen was apparent. Hydrogen serves as the facilitating and throttling agent in the chemical reaction. Providing hydrogen to the reaction is a necessary function, and understanding its disposition in the reaction is the key to maintaining effective control. Therefore, hydrogen became the central focus of the display.

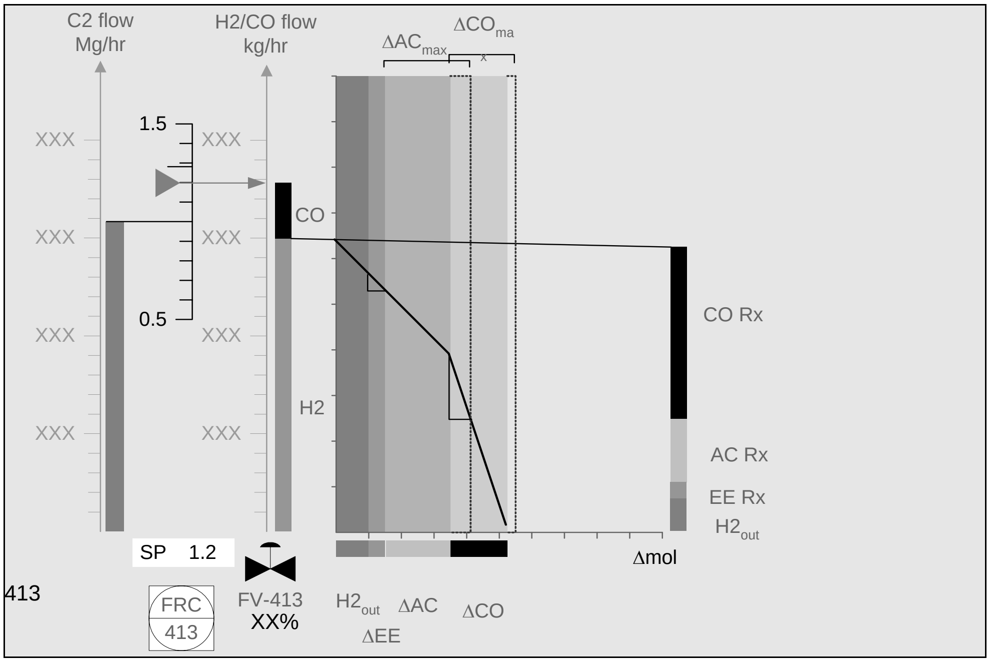

Figure 1: Balance Display, version 1.

Version 1 of the display focused on the stages of hydrogen functionality (see Figure 1). The hydrogen flow into the reactor must be regulated and accounted for in the reaction. A ratio controller (FRC) establishes a setpoint for hydrogen flow based on the hydrocarbon (C2) flow. Thus, we showed process flow (first column at left) and used a scale (0.5-1.5) to show how the setting of the FRC would result in a setpoint for the hydrogen flow (H2/CO flow). The scale was intended to move up and down with the C2 flow column. The setting of the FRC is shown on the scale with an arrow that points to the desired setpoint on the hydrogen flow column. We next drafted a graphic to show how the hydrogen was being used in the reactor. A mol-mol scale shows hydrogen coming into the reactor on the vertical scale and hydrogen “sinks” on the horizontal scale (that is, outlet hydrogen, acetylene conversion (ΔAC), ethylene conversion (ΔEE,

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and carbon monoxide conversion (ΔCO)). The thickness of three grey blocks corresponds to the number of moles of hydrogen given up to each sink. A sloped line is drawn from the hydrogen inlet point across the blocks. It descends at a slope of –1 for the first three reactions because they each use up one hydrogen mole for each mole converted. When the consumption line reaches the carbon monoxide (CO) sink block, it descends at a slope of –3 because 3 moles of hydrogen are required for each mole of CO. In other words, the consumption line reflects the stoichiometrics of the various reactions.

The widths of the three rectangles are repeated as a vertical column on the right hand side of the consumption graphic. A line drawn across the graphic from the hydrogen inflow to the stacked column represents the comparison of hydrogen inflow and known outflows. A positive (excess hydrogen) or negative (missing hydrogen) deviation of this line from the horizontal represents a discrepancy in the hydrogen accounting.

We produced paper prototypes of our design concept and conducted design walkthroughs with two process engineers and two senior operators. The engineers found that the hydrogen balance design showed graphically what they had been trying to teach operators about the reaction process. However, they pointed out that the CO reaction represented in the graphic does not take place as called out in the work domain analysis. The correction to this error is shown in version 2. The operators commented that the balance graphic gave them greater insight into a process that they knew from experience was central to the effective operation of the reactor. We were warned that small deviations in the balance were common and important. They were also interested to see the behaviour of the FRC graphic and the balance graphic with actual process data. This would turn out to be important because a casual observer later noted that the FRC design was flawed. Notably, neither the designers nor the domain experts detected this error until several weeks later.

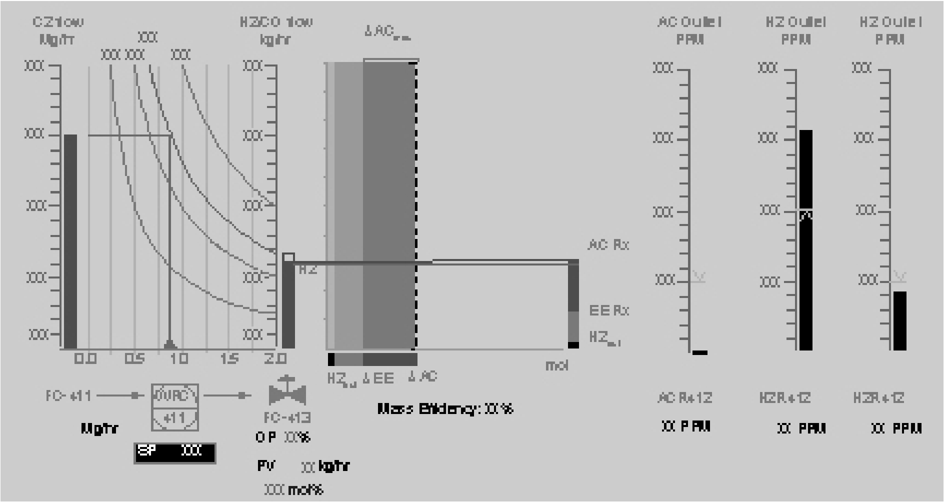

Figure 2: Hydrogen Balance Display, version 2.

In version 2 (Figure 2), we introduced a new graphic for the representation of the FRC. The original FRC concept showed an additive relationship between C2 flow and FRC setting when a multiplicative relationship was required. The replacement graphic shows the setpoint for the FRC in the form of a triangle along the horizontal axis of a two-dimensional plot. The vertical axis represents the C2 flow. A series of constant value curves is drawn in this surface, such that the product of the values of the horizontal and vertical axes meets on that curve. The current value of that product should be the setpoint for the H2/CO flow. This is represented by the green curve, which intersects the H2/CO scale at the intended setpoint. The graphic thereby allows the user to assess whether the control task of regulating the hydrogen to process flow ratio is being met.

Note also in version 2 that the CO reaction components no longer appear in the balance graphic and the consumption slope has been removed. This line was only marginally useful given that all of the reactions taking place in the reactor have the same stochastic relationship, thus resulting in a monotonic consumption curve.

Based on the feedback from our initial design review, we expanded the scope of the display to address not only the hydrogen reactions, but also the performance of the reactor as a whole. Three analyzer columns were added on the right side of the display, thereby enabling the design to display the inlet, reaction, and outlet process flow through the reactor.

Once the revisions were complete, a rapid prototyping tool was used to create a dynamic Flash-based prototype driven with recorded process data. Twenty-two professional operators conducted a design walkthrough with the prototype display. Many of the operators requested a single graphic to monitor all of the functions related to the reactor performance. This included the settings of upstream and downstream control valves that had been represented in other displays.

In version 3, in response to operator requests, we moved information from other views into the reactor view to support the control task. We produced a design specification for the view and hired a software contractor to implement it (see Figure 3).

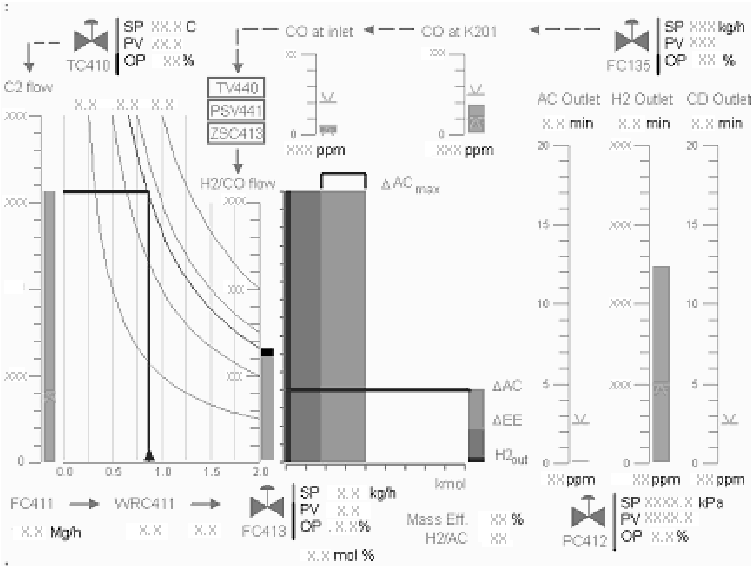

Figure 3: The implemented version (version 3) of the display.

3 Results

We were able to successfully apply EID to the design of a graphical user interface for an industrial process. A subsequent simulator evaluation of the displays confirmed that the designs led to

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improved operator performance on representative control tasks (Jamieson, 2002). We did not encounter any substantial difficulties in scaling up the framework and we have shown that EID can make valuable contributions to industry design problems.

One of the many challenges that we faced was prototyping and implementing the atypical designs. Although we knew that paper prototypes are useful tools for evaluating more traditional designs (Nielsen & Mack, 1994), we were unsure if they would work well with the novel integrated graphics that characterize ecological interfaces. In fact, they were almost as effective as the Flash prototype. Moreover, implementing the Flash prototypes proved difficult and time-consuming, and they were only of marginal added value compared to the paper. The implementation challenge also carried through to the final user interface controls. We had to identify an implementer who was able to develop new and unusual widgets from scratch, as well as establish the data structure to connect the controls to an instrumentation and control system. The short supply of implementers with this skill set should be considered in attempting to practice EID in an industry setting.

Despite these challenges, applying EID within a user-centred design approach led to improved display designs. The task analysis (which is not a traditional component of EID; see Jamieson et al, 2001) and design walkthroughs provided valuable feedback from domain experts. We believe that this represents the first case in which representative users were consulted in the design of an ecological interface. Previous applications of the framework have typically been completed for work domains for which expert users did not yet exist. Thus, the present example serves as proof that the user-centred design approach compliments the EID approach.

4 References

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