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The Impact of Ecological Displays on Operator Task Performance and Workload

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OECD HALDEN REACTOR PROJECT

THE IMPACT OF ECOLOGICAL DISPLAYS ON OPERATOR TASK PERFORMANCE AND WORKLOAD

by

Nathan Lau, University of Toronto & OECD Halden Reactor Project; Gyrd Skraaning jr., OECD Halden Reactor Project; Greg A. Jamieson, University of Toronto; and Catherine M. Burns, University of Waterloo

April 2008

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Institutt for energiteknikk
OECD HALDEN REACTOR PROJECT

Title

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Abstract:

Laboratory studies have shown that ecological interfaces can enhance operator performance in process control. However, the nuclear industry needs empirical evaluation in representative settings in order to justify the adoption of the Ecological Interface Design (EID) framework. This report presents an empirical study as a first step towards the validation of EID in the nuclear domain. The empirical study compared the operator task and workload performance of ecological displays against mimic-based displays for the turbine side of a boiling water reactor plant. The results suggest that ecological displays have a marked advantage in supporting operator performance during monitoring for unanticipated events as compared to mimic-based displays. This study provides supporting or validation evidence that EID is effective at a scale and level of complexity that is representative of nuclear power plant operations.

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1. INTRODUCTION

1.1 Background

Ecological Interface Design (EID) is a theoretical framework for designing human-computer interfaces for complex socio-technical systems (Burns & Hajdukiewicz, 2004; Vicente & Rasmussen, 1992). The framework explicitly aims to support worker adaptation, especially during unanticipated events, thereby facilitating robust designs of user interfaces. Research on the EID framework has progressed significantly since its first introduction over fifteen years ago (Rasmussen & Vicente, 1989). Proof-of-concept ecological interfaces have been reported in many domains (see, Burns & Hajdukiewicz, 2004) and performance benefits have been demonstrated in many empirical studies (see, Vicente, 2002). Despite its theoretical strength and accumulating research evidence, however, EID has yet to be widely adopted by industry.

One factor precluding industry from gaining knowledge and confidence to adopt EID is a shortage of representative studies that discuss the verification and validation of design products in specific industrial settings. Verifying examples are critical to demonstrate applicability of the design framework while validating studies are crucial to confirm performance benefits. To support human-system interface (HSI) development in upcoming modernization and construction projects, we conduct research on both the applications and performance benefits that EID could practically introduce to the nuclear industry.

The research to investigate the practical benefits of EID for the nuclear industry is achievable through a representative setting (i.e., high-fidelity simulator and licensed nuclear power plant operators) provided by the Halden Reactor Project. We began with applying EID to the turbine side of a boiling water reactor (BWR) simulator and analytically demonstrating that the framework specifies information requirement and design principles that could complement current design and verification practices (Welch et al, 2007; Lau et al., in press). Following our investigation into EID applications was an empirical evaluation of the ecological displays relative to mimic-based displays. Skraaning et al. (2007) reported the methodological details of the evaluation and the situation awareness results (also see, Burns et al., in review).

This report presents further analysis and results of the human performance data collected from our empirical evaluation of EID. We begin with an EID literature review to illustrate the paucity of empirical studies representative of nuclear process operations that could be impeding the adoption of the design framework. Following the literature review is an overview of the experiment, of which the details are documented by Skraaning et al. (2007). Then, we turn to unique contribution of this report - the analysis and results of operator task performance and workload supported by ecological displays. The report concludes with a discussion of the results and their implications to the nuclear domain.

1.2 Review of EID Research – Empirical Studies

The empirical foundation of EID is built upon studies of process control ‘micro world’ simulations (Garabet & Burns, 2004; Reising & Sanderson, 2004; Reising & Sanderson, 2002; St-Cyr, 2006; Vicente, 2002), which have served as experimental platforms for a large number of studies covering many aspects of the interface design problem. Vicente (2002) provides a comprehensive review of these results, concluding that EID can lead to robust and usable interfaces. Participants are frequently more effective and efficient in completing laboratory tasks using ecological interfaces than with traditional (i.e., mimic-based displays) interfaces under unanticipated or uncommon conditions. Unanticipated events typically force operators to engage knowledge-based work, involving reasoning about safety and operating goals, and the sometimes conflicting means of achieving them (see, O'Hara, Higgins, Persensky, Lewis, & Bongarra (2004); also refer to Rasmussen (1983) on knowledge-based behaviours). The advantages with knowledge-based tasks provided by ecological displays are usually obtained without performance decrements under anticipated conditions when operators typically engaged in procedure-guided tasks, primarily involving rule-based-decision-making (see, O'Hara et al. (2004); also refer to Rasmussen (1983) on rule-based behaviours).

These empirical studies, however, lack the scale and complexity needed to evaluate the performance benefits of EID in the process industries. Nevertheless, they motivate continued research, including proof-of-concept applications and a selection of empirical studies.

There are several ecological interfaces that are representative industrial process systems in the literature (see, Burns & Hajdukiewicz (2004) for a comprehensive review), and three were empirically evaluated. Jamieson (2007; Jamieson, Miller, Ho, & Vicente, 2007) developed an ecological interface for a simulated petrochemical process and evaluated it in a full-scope simulator with licensed operators. The results corroborated many of the findings of the foundational studies, supporting the generalization that ecological interfaces improve monitoring and control performance in comparison to conventional computer interfaces.

The two other EID empirical studies are situated in the power generation domain. Ham and Woon (2001a, 2001b) presented an empirical evaluation of ecological interface content in a nuclear plant simulator. They found that student participants presented with the full suite of information identified by a Work Domain Analysis were more effective at diagnosing unfamiliar faults than those presented with a subset that was similar to the information content identified by task-based approaches. Because the evaluation was limited to the content (i.e., there was no manipulation of graphical representation), the study did not completely assess the EID framework, which typically employs configural graphics to communicate system information. In brief, their empirical studies could only lend partial support for EID.

Burns (2000a, 2000b) developed and implemented three ecological displays based on a single work domain analysis for a simulated prototype fossil fuel power plant. Each of the displays used a different information integration and navigation technique (as opposed to the two previous investigations where alternative interfaces were developed through different design approaches). The displays afforded an empirical comparison of these techniques employing university students as participants. While the findings provide valuable guidance for the design of interfaces for the process industries, they are not intended to serve as validation evidence for performance benefits of ecological interfaces over conventional interfaces.

1.3 Implications for the nuclear industry

Empirical findings in representative settings to date support the conclusion that the benefits of EID observed in micro worlds can generalize to real world applications for process control. However, as presented by the literature review above, the weight of empirical evidence collected under conditions representative of the industrial environment and user population is insufficient to validate the claims of EID and facilitate broad adoption in industry.

This shortage of representative empirical evaluations challenges the adoption of EID in the nuclear industry. To acquire support from management and regulators, demonstrating the ability of ecological displays to meet operational and safety goals or to obtain benefits over existing technology is crucial. Given the validation evidence currently available, it is unrealistic to expect widespread adoption of EID in the nuclear industry. In effect, the nuclear industry would not be able to capitalize on the potential value of EID providing support for operators to cope with unanticipated events (O'Hara, 1999; O'Hara et al., 2004).

1.4 Overview of the current study

To support the industry in managing unanticipated events, we conducted a high-fidelity simulator study recruiting licensed operators to begin the validation process of gathering empirical evidence on EID that is representative of the nuclear operations. The study yielded data on the level of support provided by ecological displays for several human performance constructs (e.g., workload, situation awareness). This report specifically presents the empirical evidence on the relative levels of operator performance for ecological displays in comparison with mimic-based displays during realistic nuclear power plant events.

The remainder of the report is organized as follows: Section 2 describes the data collection method including participants, experimental design and manipulations, measures and procedures. Section 3 presents statistical analysis and results on task performance and workload. Section 4 discusses the implication of the results, limitation of the study and future research for the nuclear industry.

2. METHOD

2.1 Participants

Six licensed operator crews (n=6) were recruited from a boiling water reactor power plant identical to the simulated process. Each crew consisted of one reactor operator (RO) and one turbine operator (TO), responsible for the reactor and turbine side of the simulated process, respectively. In two cases within this study, participants currently working as ROs operated the secondary side. This substitution should not affect generalization of the results given that all ROs must previously or currently hold TO licenses. Furthermore, two of the participants that were scheduled to act as Reactor Operators were unable to attend. Consequently, two participants act as Reactor Operators twice. This compromise should not have substantial effect on the results because the experimental analysis only pertains to the performance data collected on the TOs. (The performance data on the ROs was not analyzed here.)

2.2 Test and simulate environment

The experiment was performed in the HAlden Man-Machine LABoratory (HAMMLAB) on a high fidelity simulator of a 1200 MW boiling water reactor with one turbine and a feedwater tank.

HAMMLAB has three operator workstations and a large-screen display (Figure 1). The RO and TO workstations were used for this study and had eleven 19" LCD screens each (Figure 2). On seven of the screens, the operators could select freely among 64 mimic-displays that represented the sub-systems of the plant. The mimic-displays gave access to detailed process information and were used to interact with the process. The operators could also generate trend graphs of selected system parameters on these screens. (Note that these trend diagrams require operators to select the system parameters and differ from the mini and pop-up trends which plot preselected parameters.) The remaining four screens on each workstation were spatially dedicated to alarms and event lists. The large-screen display in the middle of the Control Room provided a mimic-based overview of the plant for both operators. Navigation was carried out via keyboard and mouse. The operating procedures used in the experiment were standard paper-based procedures developed for the simulated plant.

An experiment leader, process expert, and laboratory technician managed the simulator, scenarios, and data collection from the Observation Gallery (see, Figure 1). Operator interactions with the interface were logged in the simulator, while activities in the control room were audio and video recorded.

The process expert had several important roles in the experiment, including interface design, scenario development and human performance evaluation. Our expert was an engineer with 15 years of experience from a Swedish nuclear power plant, working 4 years as Turbine Operator, 4 years as Reactor Operator, 4 years as Shift Supervisor, and 3 years as responsible for reactor core operation. During these years he was also involved in the construction of the plant, simulator development and operator training. In addition, he had 10 years of experience as a process expert and control room systems designer in HAMMLAB, and contributed strongly to the development of the Forsmark 3 simulator used for this experiment.

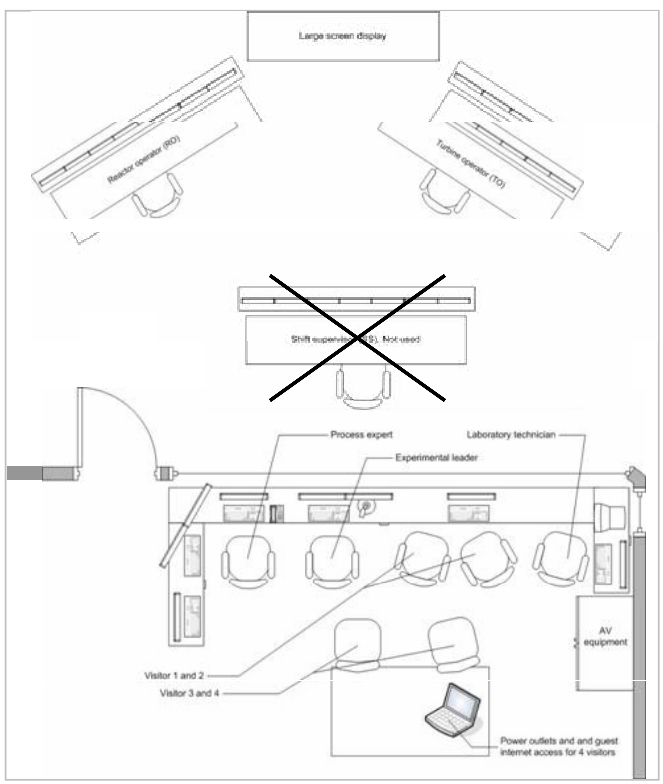

Figure 1: HAMMLAB Control Room and Observation Gallery

Figure 2: LCD panel layout for the turbine operator workstation in the Ecological display condition.

2.3 Experimental Manipulations

This study consisted of three experimental manipulations – display types, scenario types and scenario phases.

2.3.1 Display Types

Three display types – Traditional, Advanced, and Ecological – were selected for comparison. Prior to illustrating their distinct characteristics, we first describe the shared features of the interfaces.

As mentioned earlier and illustrated in Figure 2, the design scope was limited to the turbine side. Given this scope, alarm information was communicated in the same manner across the display conditions (i.e., they have the same alarm displays). Furthermore, all three types of displays share the general layout shown in Figure 3, in which the gray areas are the same across the three display types. The interaction style was also consistent across display type. Specifically, operators could click on a plant component icon in the format field of any display to access/view the equipment status and related control variables that appeared in the automatic and/or process control fields. To execute control actions, operators could key in desired values in corresponding variable entry fields. In contrast, for displays that were within the design scope of the ecological displays (i.e., the turbine side), the format fields (i.e., the white area in Figure 3) varied according to the description as follows.

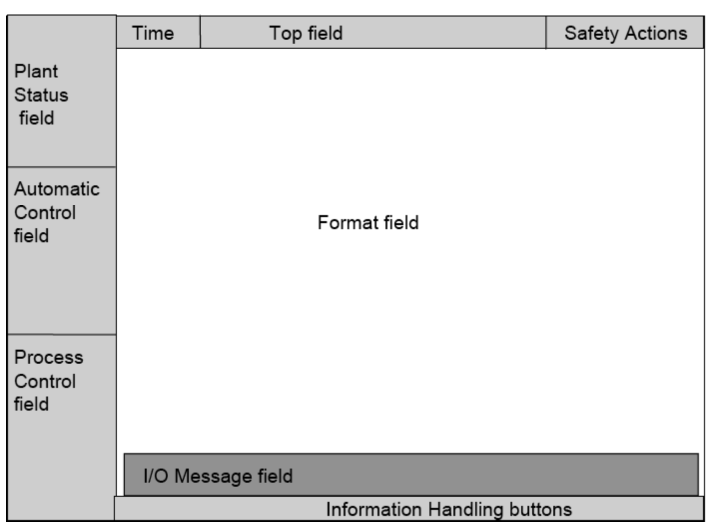

Figure 3: Display layout.

2.3.1.1 Traditional Displays

The Traditional displays are the computerized version of the hard-wired wall panels originally installed in the operating nuclear plant (Figure 4). The Traditional displays roughly represent the "state-of-practice" design, characterized by mimic diagrams of the facilities with numeric outputs of instrumentation (i.e., mimic-based displays). Although the design process might not adhere strictly to a particular framework, the design was largely informed by task analyses and possibly some user input as mandated by regulators (O'Hara & Brown, 2002).

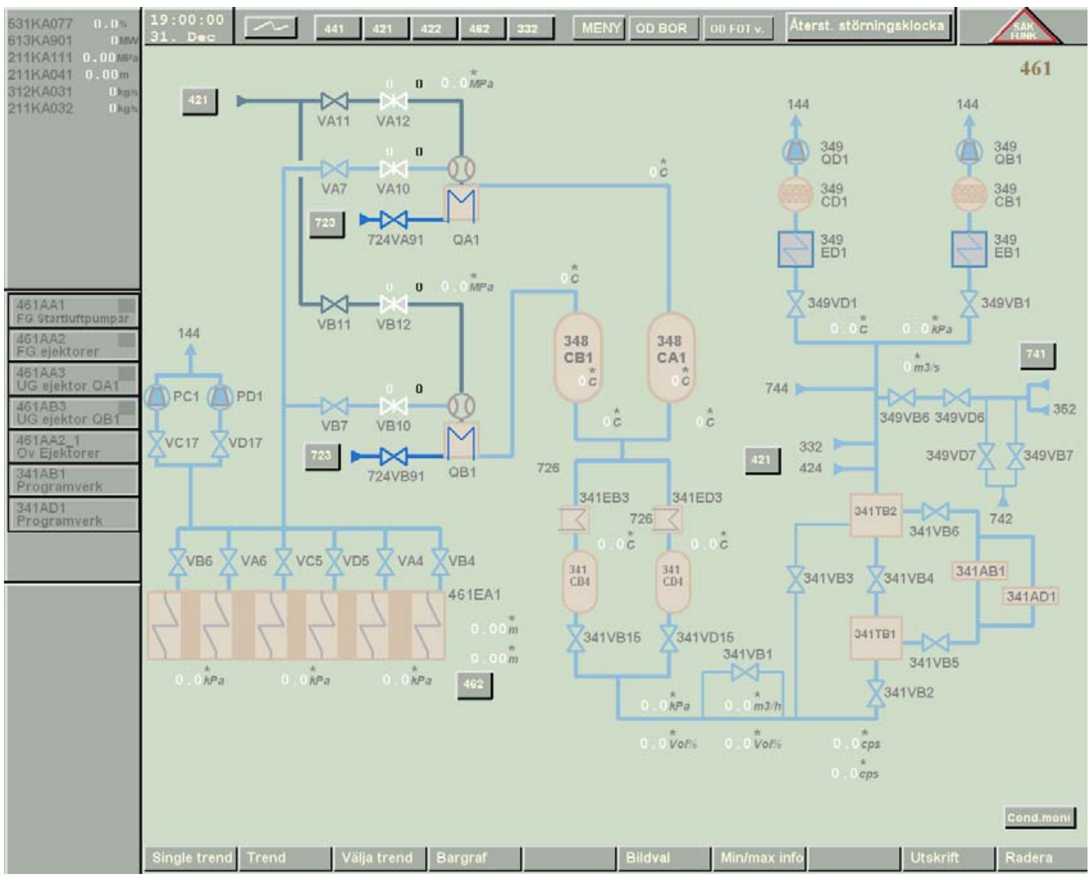

Figure 4: An example of a Traditional display.

2.3.1.2 Advanced Displays

The Advanced displays are a graphically enhanced version of the Traditional displays (Figure 5). The Advanced displays retain the mimic-diagrams of the Traditional displays; however, they also contain some configural graphics (e.g., Bennett & Flach, 1992; Bennett, Toms & Woods, 1993) and "mini-trends" strategically developed or inserted by process experts. Skraaning & Nihlwing (2008) provides a detailed account of the graphical enhancements over the Traditional displays. For this display condition, the large screen display contained some advanced visualization features that were absent from both Traditional and Ecological display conditions in addition to the condensed mimic diagrams with key instrumentation outputs. The Advanced displays generally represent the latest implemented design, characterized by some novel visualization or leading edge features on top of mimic-diagrams with numerical outputs of instrumentation. The

Advanced displays resemble the displays developed in many control room modernization projects. Though potentially similar to configural graphics typifying ecological displays, the new visualizations in the Advanced displays are based on expert opinions that are often considered as products of a user-centered approach and evolutionary design strategy.

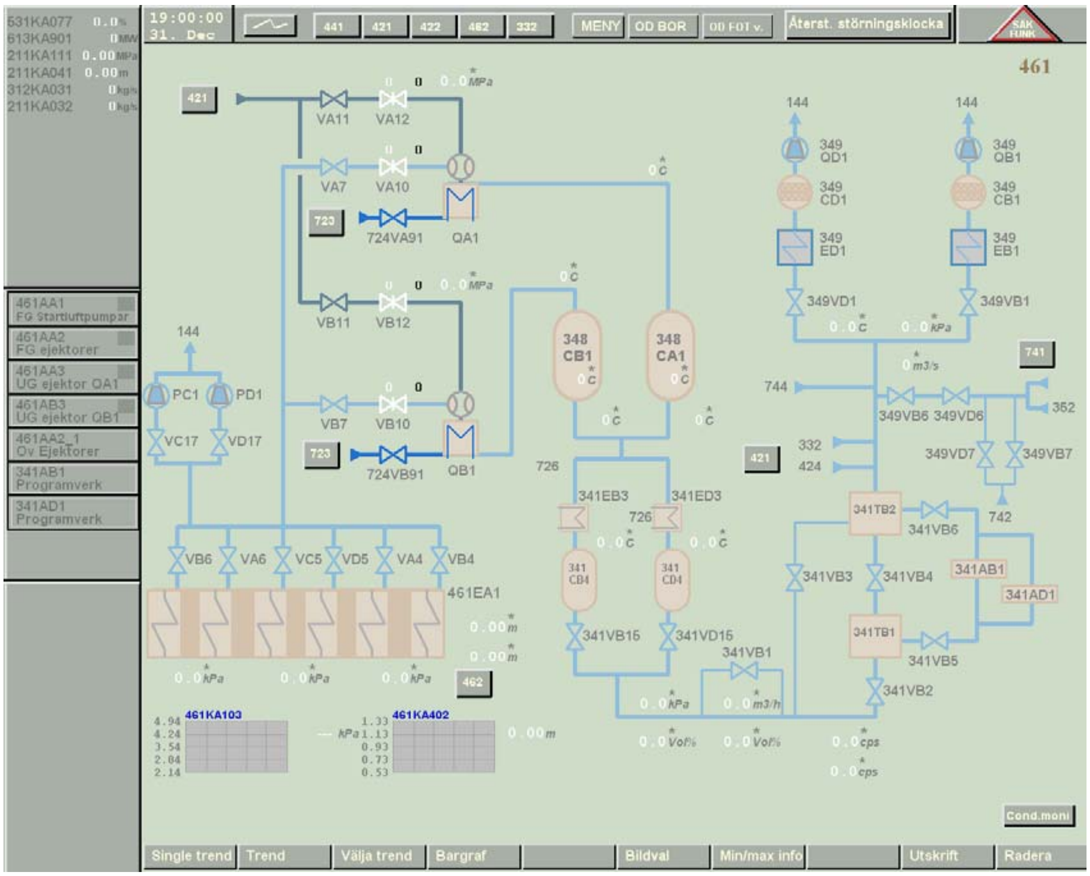

Figure 5: An example of an Advanced display.

2.3.1.3 Ecological Displays

The Ecological displays were designed according to the EID framework and described in details by Welch et al., (2007) and Lau et al., (in review). In brief, EID is a theoretical framework for design human computer interfaces for complex systems that claims to enhance operator performance by specifying information requirements and perceptual features based on formative work analysis and cognitive controls, respectively. Figure 6 shows an example of an ecological display. As mentioned, the design scope was limited to the secondary side. The participants had access to the Traditional displays for plant processes that were not represented by the Ecological displays. Furthermore, the operators had access to the large screen display in the Traditional display condition.

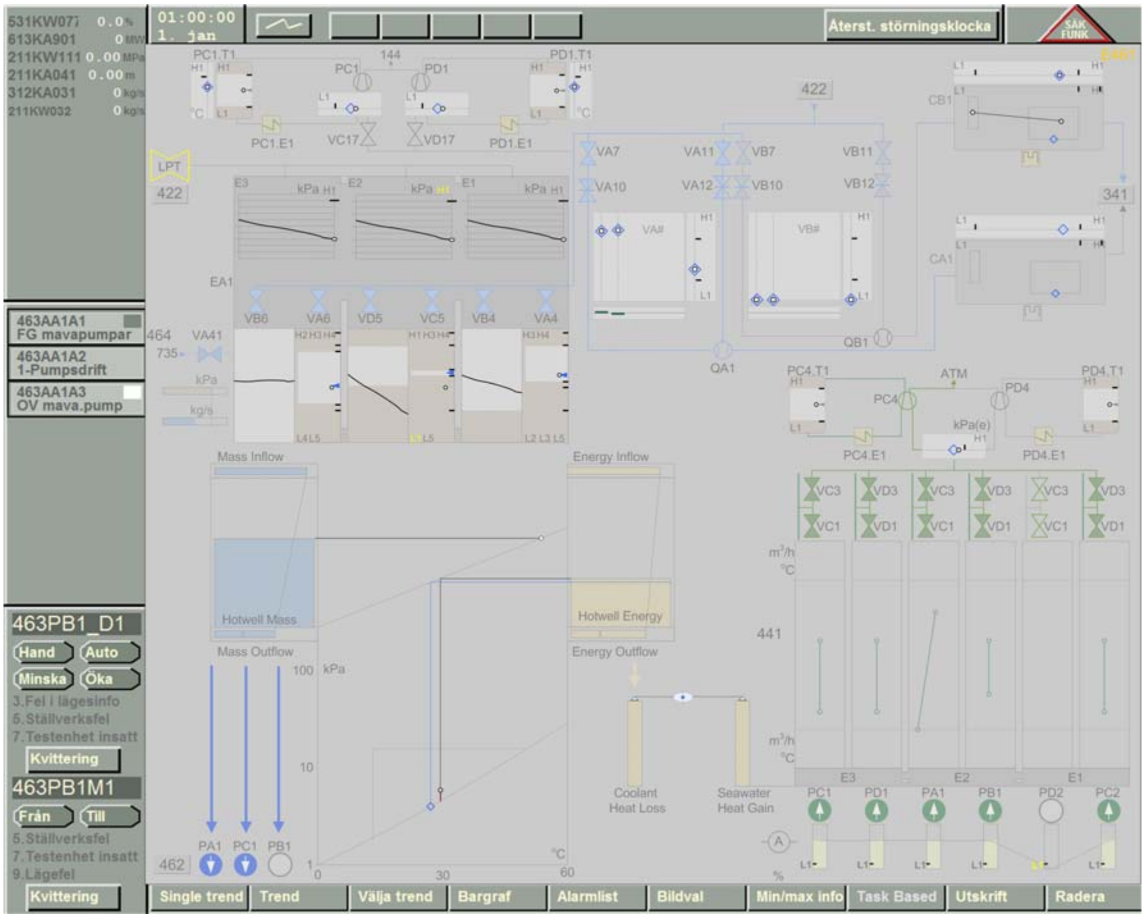

Figure 6: An example of an Ecological display.

2.3.2 Scenario Type

This study contained three Procedure-guided and three Knowledge-based scenarios. For the purpose of this study, Procedure-guided scenarios were defined by a set of disturbances that could be resolved by referencing plant procedures. Scenarios in which disturbances could not be resolved by procedures were classified as Knowledge-based. In other words, equipment failures anticipated by the utilities and job responsibilities familiar to operators characterized the Procedure-guided scenarios, while unanticipated and unfamiliar ones characterized the Knowledge-based scenarios (Table 1). Refer to Skraaning et al. (2007) for the details of each scenario.

Table 1: Scenarios.

	Procedure-guided	Knowledge-based
1	Leakage at the intermediate superheater at 109.3% power level	Turbine trip while the generator is connected to the grid at 109.3% power level
2	Drain route switch and pre-heater bypass reset at 20% power level	Leakage at the condensate cleaning building at 109.3% power level
3	Drift of an instrument at 44% power level	Sudden and dramatic increase of seawater temperature at 109.3 power level

2.3.3 Scenario Phase

Each scenario started with a "Detection" phase, a time period just before the first alarm sounded, and then ended with a "Mitigation" phase that consisted of all subsequent events. (Figure 7 illustrates the detailed structure of the scenarios.) The two phases afforded separate assessments of the effectiveness of the displays in supporting both monitoring and intervention.

2.4 Experimental Design

A 3x2x2 within-subjects design was employed with treatments of display type (Traditional, Advanced and Ecological), scenario type (Procedure-guided and Knowledge-based), and scenario phase (Detection and Mitigation). The treatments were completely crossed and counterbalanced using a Latin-square technique. Table 2 presents the final experimental design and the assignments of the six crews to the six scenarios that were divided into two phases (N=72).

Table 2: The final experimental design: Display Type × Scenario Type × Scenario Phase.

The independent variables were completely crossed. The run orders were counter-balanced using a Latin square. (Note that Scenario 1, 2 and 3 are Procedure-guided scenarios; whereas, Scenario 4, 5 and 6 are Knowledge-based scenarios.)

Crew	Procedure-guided Scenarios						Knowledge-based Scenarios					
	Traditional Displays		Advanced Displays		EID Displays		Traditional Displays		Advanced Displays		EID Displays	
	Det. Phase	Mit. Phase	Det. Phase	Mit. Phase	Det. Phase	Mit. Phase	Det. Phase	Mit. Phase	Det. Phase	Mit. Phase	Det. Phase	Mit. Phase
1	Scenario 1		Scenario 2		Scenario 3		Scenario 5		Scenario 6		Scenario 4	
2	Scenario 3		Scenario 1		Scenario 2		Scenario 5		Scenario 4		Scenario 6	
3	Scenario 3		Scenario 1		Scenario 2		Scenario 4		Scenario 5		Scenario 6	
4	Scenario 3		Scenario 2		Scenario 1		Scenario 5		Scenario 4		Scenario 6	
5	Scenario 3		Scenario 2		Scenario 1		Scenario 4		Scenario 5		Scenario 6	
6	Scenario 1		Scenario 3		Scenario 2		Scenario 4		Scenario 6		Scenario 5	

2.5 Hypotheses

The theoretical foundations of EID (Vicente & Rasmussen, 1992) and previous empirical results (Jamieson, 2007; Vicente, 2002) suggest that Ecological displays would support operators better than both Traditional and Advanced displays. In particular, the performance advantage of the Ecological displays was anticipated to be most pronounced in Knowledge-based scenarios, in which problem solving would be the primary means to resolving process disturbances.

2.6 Measures

2.6.1 Actual Task Performance

Actual task performance was captured and quantified using the Operator Performance Assessment System (OPAS; Skraaning jr., 1998, 2003; Skraaning jr. et al., 2007). OPAS provides a structure for the assessment of whether operators carry out their task work in accordance with scenario solutions prescribed a priori by experts in control room operation.

Prior to data collection, process experts analyzed the scenarios and developed optimal solutions by identifying items that expressed the desired performance. In principal, any discrete performance criterion that can be verified against actual operator data (i.e., observable operator behaviors) may serve as a performance item. In general, items that could differentiate between levels of task performance across experimental conditions typically relate to omissions, commissions, response time, and strategies (Table 3). Performance items may also be perceived in the light of process operations such as safety, production, and preservation activities (Table 4).

Table 3: Generic example of OPAS items. (Scores values in square brackets.)

Omission Example	**Detect a specific alarm**
	a) No [0]
	b) Yes [2]
Commission Example	**Performing the following**
	a) Do not start or start wrong pump [0]
	b) Start the correct pump without informing field operator [2]
	c) Start correct pump and inform field operator [3]
Response Time Example	**Close a specific valve after a specific alarm sounded**
	a) Do not close or close after 8 min [0]
	b) Close between 5 to 8 min [1]
	c) Close between 3 to 5 min [2]
	d) Close within 3 min [3]
Strategy Example	**Prioritize activities appropriately**
	a) Fail to stop or notice leakage [0]
	b) Stop leakage after managing sub-disturbances [1]
	c) Stop leakage before managing sub-disturbances [3]

Table 4: Types of OPAS items from an operational perspective.

Activity Types	**Descriptions**
Safety	Activities that prevent and mitigate nuclear transient, disturbances and accidents
Production	Activities that maintain the desired level of electricity generation
Preservation	Activities that ensures that the mechanical components of the plant are not exposed to unnecessary physical stress

Process experts specify different performance items (i.e., content of the task performance construct) according to the defining characteristics of the scenarios. In other words, performance items vary with scenarios according to the judgments of the experts. The rationale for such reliance on experts is that human task performance in complex operating environments is comprehensible only to process experts (as suggested by past research (Anderson, 1985)). Furthermore, the contexts or scenarios of nuclear operations are very diverse such that predefined constructs could often include irrelevant and/or exclude relevant aspects of performance for a given scenario, constraining the practical values of the measurements.

For this experiment, one process expert analyzed the scenarios and specified the performance items. A simple scoring system was used, where the operators earned points for completing performance items. Each item depicted alternative operator activities that were rewarded by 0, 1, 2 or 3 points. In this experiment, the performance items may be classified as one of the four categories: detection, inference, action and teamwork/communication[1] (see examples in Table 5).

Table 5: Examples of OPAS performance items in the experiment. (Scores values in square brackets.)

Detection Example	**Detect and take care of the problem in the turbine plant main stream systems 421**	
	c)	Does not take care of the 421 problem correctly [0]
	d)	Detects and takes care of the 421 problems correctly with in 7 minutes [1]
	e)	Detects and takes care of the 421 problems correctly with in 5 minutes [2]
	f)	Detects and takes care of the 421 problems correctly with in 3 minutes [3]
Inference Example	**Make inference about leakage in the steam super heater 422EA1**	
	d)	No or wrong inference [0]
	e)	Partly correct inference [1]
	f)	Mostly correct inference [2]
	g)	Fully correct inference [3]
Action Example	**Close water level regulating valve for the feedwater tank 462VA5**	
	e)	No action [0]
	f)	Close 462VA5 in order to manually close 332VB2 [1]
	g)	Close 462VA5 in order to manually close 332VB2, but before the low level alarm in the feedwater tank sounded [3]
Teamwork Example	**Inform reactor operator about the upcoming power reduction**	
	d)	No [0]
	e)	Yes [3]

During the experiment, a process expert registered the points earned by operators in completing the predefined activities within each performance item based on observations of operator verbalization, physical behaviours, problem solving, and system states. Studies have shown that real time expert rating is comparable to objective data logs (e.g., simulator logs and video recordings) and that a single expert rater is adequate given the high inter-rater reliability (Skraaning jr., 2003) of the OPAS instrument. The employed performance index is the unweighted average of all performance items defined for a scenario.

[1] Performance items were classified during the analysis phase. There was no a priori classification system that prompted the process expert to formulate any specific type of performance items.

The OPAS index reflects the discrepancy between operator performance and predefined optimal solutions to scenarios. Due to its relativistic nature, the OPAS index cannot establish any general acceptance criteria, as it is only meaningful for comparisons between indices across situations. Nevertheless, operator performance relative to the optimal level can be psychologically meaningful. OPAS assesses the degree of conformance with performance expectations that remain constant across task conditions; thus, the raw scores originating from different scenarios can be compiled into one performance index. In addition, OPAS is similar to training and licensing assessment situations in the nuclear domain, for which human performance constructs, are often ill-defined and may be difficult for non-experts to understand due to domain complexity.

The ill-defined nature of human performance in complex domains is partially attributable to the fact that measures of task performance often include multiple and interacting aspects of human performance. Some aspects of human performance, such as expertise or past experience, are not generally consider part of task performance but significantly affect, though not determine, task performance. In other words, task performance measures often cannot distinguish between different aspects of human performance, even though these aspects may be psychologically or conceptually distinct. For this reason, task performance could be interpreted from multiple perspectives depending on the combinations of aspects of interest.

In this study, we are particularly concerned with distinguishing between task performance and workload. Workload is largely driven by the nature of the scenarios, which also determines the OPAS performance items. For some scenarios, operators may experience high workload from completing many relatively simple performance items in a short amount of time. Other operators may experience high workload from completing only a few complex performance items. In either case, operators need to overcome workload demand to achieve high OPAS indices. From one perspective, workload is an integral part of task performance as both are always present when performing work. From another, workload remains different from task performance, as workload could *mediate* but not determine task performance. To illuminate the performance data from both perspectives, the results include the effects of experimental manipulations on (a) Workload and (b) Actual task performance controlling for the mediating effect of Workload (see *4. Discussion*).

2.6.2 Workload

Workload is generally accepted to have a significant impact on performance. Improved task performance at the expense of higher workload is usually not desirable; thus, we collected workload data using a subjective task-complexity scale developed by the OECD Halden Reactor Project (Braarud, 2000). The scale is a self-rating instrument focusing on task-related difficulties that control room operators experience while they work. Participants rate five items (Table 6) in a seven-point Likert scale anchored by 'very difficult' (1) and 'very easy' (7). Several psychometric evaluations and experimental studies indicate that the scale is more reliable and predictive of task performance in representative nuclear process control settings (Skraaning jr. et al., 2007) than the NASA-TLX (Hart & Staveland, 1988). Braarud & Brendryen (2001) discuss the subjective task-complexity scale in detail.

Table 6: Workload items of the subjective task-complexity scale.

Workload items	How difficult was this scenario period with respect to:
Item 1	Vague or ambiguous process displays, misleading or missing process information
Item 2	Ambiguous, misleading or missing feedback on operator actions
Item 3	Time for planning and controlling the work
Item 4	May parallel tasks (several disturbances or process events) that complicated the execution of every single task
Item 5	Collection and utilization of much information to perform the work

2.7 Procedure

The participation of each crew was divided over three consecutive days. The first day was dedicated to the training program after obtaining informed consent and demographic information. Six hours of training occurred on the first day as outlined in Table 7. The second day started with a one-hour training session to refresh the materials presented on the first day, followed by three scenarios with fifteen-minute breaks in between. The third day started with three scenarios also with fifteen-minute breaks in between, followed by a debriefing/closing session.

Table 7: Key participant activities of the experiment.

	Activity	Day	Time (min)
1	Familiarizing with the facility, interface navigation, alarm systems, large screen displays	1	60
2	Training on the Traditional and Advanced interfaces	1	60
3	Training on the differences between physical/home plant and simulated plant	1	30
4	Training on the data collection procedures	1	30
5	Training on the Ecological interface	1	180
6	Re-training on Day 1 materials prior to data collection	2	60
7	Trial 1	2	30-45
8	Trial 2	2	30-45
9	Trial 3	2	30-45
10	Trial 4	3	30-45
11	Trial 5	3	30-45
11	Trial 6	3	30-45
12	Debriefing	3	45

For all scenarios, crews were asked to maintain the original power level and safe operation. A process expert registered OPAS scores to corresponding performance items at various points of the scenarios by observing the participants while they monitored system states and resolved disturbances. The participants also responded to the subjective task-complexity questionnaire during a short simulator freeze and at the end of each scenario. The simulation freeze occurred at the end of the Detection phase, which took up the first five to ten minutes of the scenario as depicted in Figure 6. The scenario then continued with the Mitigation phase, which was marked by the onset of the first alarm within the first minute. The Mitigation phase usually lasted for 30 to 40 minutes, followed by another administration of the subjective task-complexity questionnaire at the end of the scenario.

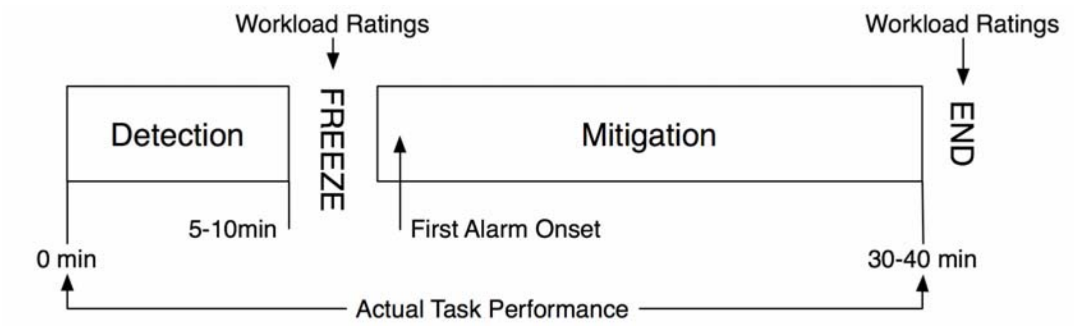

Figure 7: Basic structure of the scenarios.

3. RESULTS

Two statistical models were built to analyze the dependent variables. The first model is a three-way analysis of variance (ANOVA) on Workload, and the second model is an analysis of covariance (ANCOVA) on Actual task performance controlling for Workload.

3.1 Assumptions

The validity of the two statistical models rests on several assumptions. The normality assumption for the Workload and Actual task performance measurements is not satisfied according to the Shapiro-Wilks' W tests on the distributions for every combination of treatments (as there are only six data points for each cell given the limited access to licensed operators and the within-subject design). However, both ANOVA and ANCOVA are generally robust against the violation of normality, except for some specific characteristics of population distribution. (See [33] and [34] for a discussion of normality violations on ANOVA and ANCOVA, respectively). For the normality assumption, we thus examined the distributions for every treatment level using histograms and normal probability plots for these specific violations and did not find any major threats to the validity of the statistical results. The sphericity assumption also applies to the statistical models, which are both repeated-measures. The Mauchley's tests indicate that all effects of both models satisfy the sphericity assumption. ANCOVA requires an additional assumption – homogeneity of slopes/within group regression (also known as the parallelism assumption). The homogeneity of slopes assumption is satisfied according to visual examinations of the scatter plots, and the interaction terms between independent variables and the continuous predictor in a general linear model.

3.2 Workload – the covariate

Workload was measured by a subjective self-rating scale, which was confirmed to have a sufficiently high inter-item reliability (α=0.89) for further analysis. Workload was analyzed in an ANOVA with fixed factors of display type (Traditional, Advanced and Ecological), scenario type (Procedure-guided and Knowledge-based), and scenario phase (Detection and Mitigation), and with a random factor of crew. The ANOVA is an over-parameterized model built on Type II sums of squares.

This analysis explores the fixed effects on Workload that are helpful for interpreting the next model – an ANCOVA on Actual task performance. Workload and Actual task performance have a low correlation, $r(72)=.31$, $p<0.01$. Table 8 presents the results of the ANOVA for all effects. A significant main effect of phase (F(1,5)=23.03, p<0.01), and significant two-way interaction effects for display and phase (F(2,10)=5.39, p<0.05), and scenario and phase (F(1,5)=8.59, p<0.05) were observed.

Table 8: ANOVA results for Workload.

Fixed Effects	SS	df	MS	SS for Error	df for Error	MS for Error	F	p
Display	1.4233	2	0.7117	12.1033	10	1.2103	0.59	0.57
Scenario	0.2939	1	0.2939	1.5961	5	0.3192	0.92	0.38
Phase	22.8939	1	22.8939	4.9694	5	0.9939	23.03	<0.01
Display*Scenario	0.7078	2	0.3539	10.9122	10	1.0912	0.32	0.73
Display*Phase	3.9678	2	1.9839	3.6789	10	0.3679	5.39	0.03
Scenario*Phase	3.1250	1	3.1250	1.8183	5	0.3637	8.59	0.03
Display*Scenario*Phase	1.2700	2	0.6350	8.4967	10	0.8497	0.75	0.50

We omit the plot of the phase main effect as it provides limited and redundant information as compared to the significant two-way interaction effects. The display and phase interaction plot (Figure 8) illustrates no practical difference in Workload between the three display types in the Detection phase, but the Workload increase to the Mitigation phase is highest with the Traditional displays and lowest with the Advanced displays. The display and phase interaction effect accounts for 11% of the total variance (ω^2=0.11), which is a typical and probably medium effect size for experiments in realistic work environments.

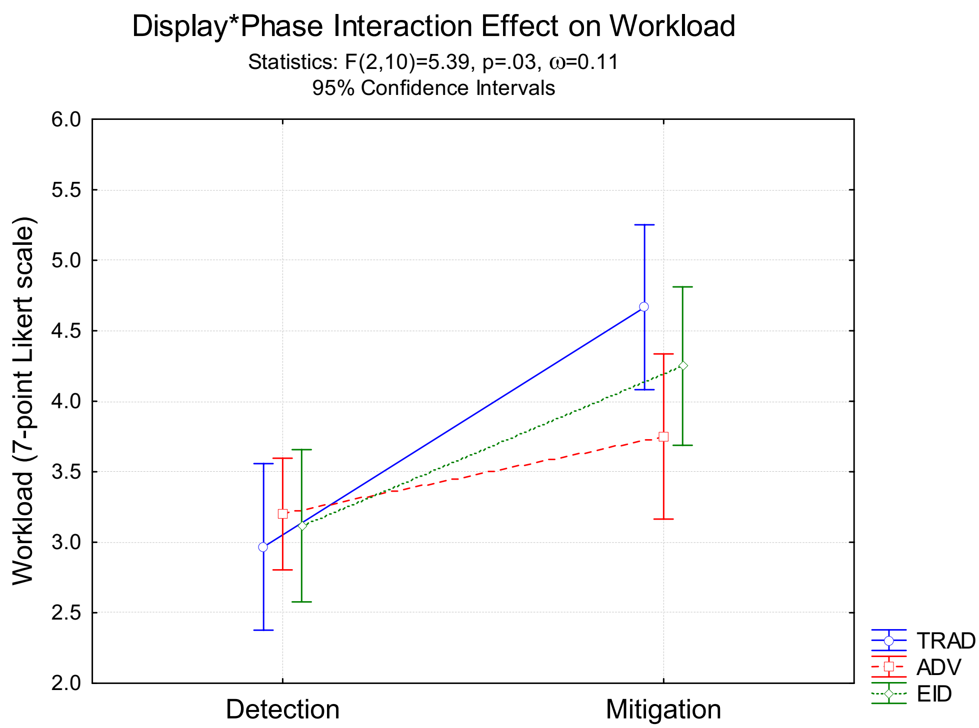

Figure 8: Interaction plot of Display and Phase for Workload. The plot is drawn according to the method proposed by Cosineau (2007) to remove within-subject variance. (Note that overlaps between confidence intervals do not necessarily indicate that the means are not significantly different. Refer to Cumming & Finch (2005) and Loftus & Masson (1994) for a discussion.)

The scenario and phase interaction plot (Figure 9) illustrates that the participants experienced less Workload during the Detection phase and more Workload during the Mitigation phase of Knowledge-based when compared to Procedure-guided scenarios in which the participants experienced more Workload during the Detection phase and less Workload in the Mitigation phase. The scenario and phase interaction effect accounts for 17% of the total variance (ω^2=0.17), which is a relatively large effect size for experiments in realistic work environments.

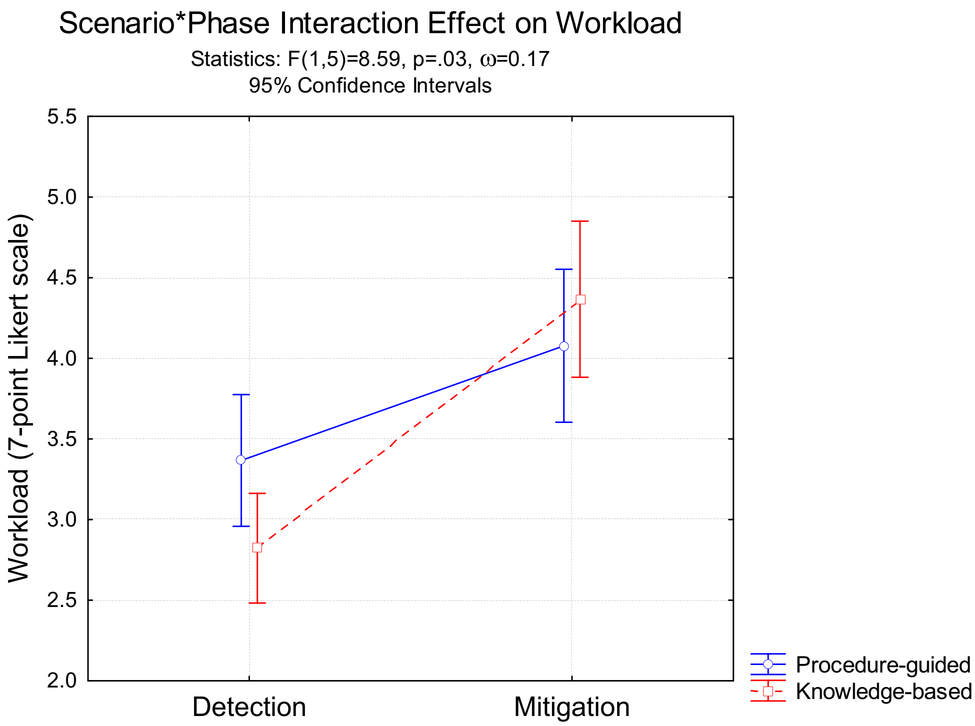

Figure 9: Interaction plot of Scenario and Phase for Workload. The plot is drawn according to the method proposed by Cosineau (2007) to remove within-subject variance. (Note that overlaps between confidence intervals do not necessarily indicate that the means are not significantly different. Refer to Cumming & Finch (2005) and Loftus & Masson (1994) for a discussion.)

3.3 Actual task performance controlled for workload

Actual task performance (i.e., the OPAS indices) was analyzed in an ANCOVA with fixed factors of display type (Traditional, Advanced and Ecological), scenario type (Procedure-guided and Knowledge-based) and scenario phase (Detection and Mitigation), a random factor of crew, and a covariate of Workload. The ANCOVA was an over-parameterized model built on Type II sums of squares.

This analysis explores the fixed effects on Actual task performance controlled for Workload, assessing the support for problem solving provided by each display type while limiting the mediating effect of task demand. The results provide empirical evidence on whether EID could introduce performance benefits according to its theoretical foundation. Table 9 presents the results of the ANCOVA for all effects. The significant effects on Actual task performance after controlling for Workload are the two-way interaction of display and phase ($F(2,10.55)=8.09$, $p<0.01$), and the three-way interaction of display, scenario and phase ($F(2,9)=6.08$, $p<0.05$).

Table 9: ANCOVA results for Actual Task Performance with Workload as the covariate.

Fixed Effects	SS	df	MS	SS for Error	df for Error	MS for Error	F	p
Display	0.9986	2	0.4993	5.0524	10	0.5052	0.99	0.41
Scenario	0.8219	1	0.8219	2.1904	5	0.4381	1.88	0.23
Phase	0.0300	1	0.0300	0.8501	5	0.1700	0.14	0.72
Display*Scenario	3.8132	2	1.9066	9.2897	10	0.9290	1.97	0.19
Display*Phase	4.3998	2	2.1999	2.7989	10	0.2799	8.09	0.00
Scenario*Phase	1.1133	1	1.1133	3.2374	5	0.6475	1.95	0.22
Display*Scenario*Phase	1.6374	2	0.8187	1.2114	9	0.1346	6.08	0.02

Because the two-way interaction only provides limited and redundant information, we present the three-way interaction plot. Figure 9 suggests that the Ecological displays enhanced Actual task performance in the Detection phase of Knowledge-based scenarios. The performance difference between interfaces in other experimental conditions appeared negligible. The three-way interaction effect accounts for 12% of the total variance (ω^2=0.12), which is a typical and probably medium effect size for experiments in realistic work environments.

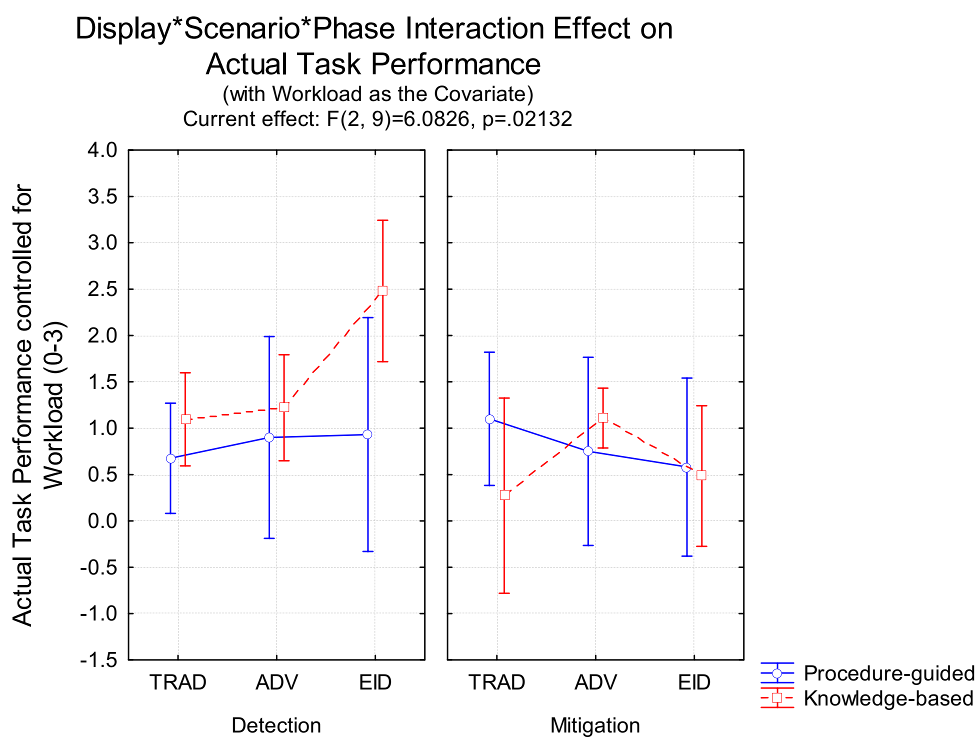

Figure 10: Interaction plot of Display, Scenario and Phase for Actual Task Performance controlled for Workload. The plot is drawn according to the method proposed by Cosineau (2007) to remove within-subject variance. (Note that overlaps between confidence intervals do not necessarily indicate that the means are not significantly different. Refer to Cumming & Finch (2005) and Loftus & Masson (1994) for a discussion.)

A post-hoc analysis using Tukey's Honestly Significant Difference (HSD) criterion for significance was conducted to confirm the performance advantage of Ecological displays in the Detection phase of Knowledge-based scenarios. As common statistical software applications do not support the post-hoc test for the above ANCOVA model, we applied a technique discussed in (Howell, 2002; Pedhazur & Schmelkin, 1991). The technique (1) formulates a new set of scores by subtracting the standardized scores between the dependent variable and the covariate, and (2) applies ANOVA on the new scores, which has already removed for the variance contributed by covariate. In our case, we built an ANOVA model on the differences between the standardized scores of Actual task performance and Workload. The final Tukey's HSD post-hoc analysis indicated that the performance of Ecological displays (M=1.81, SD=0.89) was significantly higher than Traditional (M=0.09, SD=0.72, $p<.01$) and Advanced (M=0.28, SD=0.87, $p<.01$) in the Detection phase of Knowledge-based scenarios.

4. DISCUSSION

The results have direct implications for interface design in the nuclear industry. In this section, we will first discuss effects of experimental manipulations on Workload to seek a greater understanding of the Workload covariate. Then, we examine the analysis on the Actual task performance controlling for Workload that provides the first empirical and validation evidence on EID in the nuclear domain. This section concludes with limitations, contributions and suggestions for future work.

4.1 Workload – the covariate

The analysis with Workload as the dependent measure confirms the effectiveness of the experimental manipulations. A main effect of phase was expected given that the Detection phase only required monitoring while the Mitigation phase required intervention in addition to monitoring. The scenario and phase interaction effect was also expected. As a result of low familiarity with or poor anticipation of process events, participants would be more likely to miss the early indications of system disturbances in the Detection phase of Knowledge-based scenarios than of Procedure-guided scenarios, thereby assuming normal operating states and experiencing less Workload. However, in the Mitigation phase of Knowledge-based scenarios, participants must compensate for the unanticipated disturbances and late intervention leading to a substantial increase in Workload. On the other hand, when participants could detect the early indication of disturbances in Procedure-based scenarios, the increase in Workload from the Detection to Mitigation phase was less pronounced relative to Knowledge-based scenarios.

The analysis on Workload also illustrates some differences between the display types. The results indicate that both Advanced and Ecological displays induced lower increases of Workload from the Detection to Mitigation phase than the Traditional displays. This finding is encouraging in that the new visualization techniques do not result in higher Workload. The minimum Workload increase was unexpectedly observed with the Advanced displays. We postulate that the evolutionary improvements based on the user-centered approach for the Advanced displays may be concentrated on improving efficiency and thereby reducing Workload. In contrast, the ecological approach typically emphasizes interface effectiveness against unanticipated events that does not necessarily correlate with Workload.

4.2 Validation Evidence: Actual Task Performance Controlling for Workload

The theoretical foundations and accumulated empirical results pertaining to EID indicate that the primary contribution of introducing ecological displays would be superior support for knowledge-based or problem solving tasks relative to displays based on conventional approaches.

More specifically, ecological displays could affect psychological mechanisms responsible for problem solving in ways that improve task performance beyond the benefits from the mediating effect of workload reduction. From this perspective, task performance independent of workload variation could highlight the precise effect of ecological displays intended by the EID framework.

Actual task performance, however, as defined by OPAS is likely to include the influence of workload (see *2. Method*). To limit the influence of workload while assessing the level of support for problem solving provided by the displays, we conducted an ANCOVA on Actual task performance with Workload as a covariate. The ANCOVA removed the variance associated with Workload in each scenario from the Actual task performance. In effect, the ANCOVA results provided an indication of *performance more confined to problem solving* in comparison to an ANOVA on Actual task performance.

The decision to limit the mediating effect of Workload on Actual task performance in our analysis does not imply the independence between workload and task performance in general. The integral perspective (that task performance is a synthesis of many interacting aspects of human performance) is important, particularly for a summative evaluation such as those in integrated system validation (O'Hara, Higgins, Persensky, Lewis, & Bongarra, 2004). Readers should not interpret the ANCOVA Actual task performance results independent of the ANOVA Workload results. Removing variance associated with Workload from Actual task performance through ANCOVA is a technique to clarify and emphasize of the intended effects of the EID framework rather than a proposal for altering interpretation of performance constructs within the nuclear domain. In consideration that both the Advanced and Ecological displays appear superior to the Traditional displays in terms of Workload according to the ANOVA two-way interaction effect (see section above and Figure 8), this analysis approach appeared appropriate and meaningful as new visualization techniques do not seem to induce excessive Workload.

The ANCOVA results extend the available confirming evidence on the theoretical claim (Vicente, 1999; Vicente & Rasmussen, 1992) that EID could improve operator support for knowledge-based or problem solving tasks beyond the alleviation of workload, corroborating the general findings of the previous EID studies (Jamieson, 2007; Vicente, 2002). The three-way interaction plot (Figure 10) and post-hoc analysis illustrate a marked advantage for the Ecological displays in the Detection phase of Knowledge-based scenarios over both Traditional and Advanced displays, whereas other performance differences were relatively negligible. This unique performance advantage also directly translates to the significant two-way interaction effect between display type and scenario phase.

The marked advantage for the Ecological displays in the Detection phase of Knowledge-based scenarios indicates that EID could lead to displays which better support operators in monitoring for unanticipated events or early phases of problem solving (i.e., problem identification and formulation) than mimic-based displays. Monitoring for critical events evolving from 'normal' operating states is a key part of supervisory control. Effective monitoring facilitates early intervention that can prevent process deviations developing into major disturbances or even accidents (see, Mumaw, Roth, Vicente, & Burns, 2000). Furthermore, investigations have repeatedly indicated that major accidents are often preceded by unanticipated events (J. Rasmussen, 1969; Reason, 1990). Thus, the unique advantage of the Ecological displays demonstrated in this study is encouraging in that EID could be a design solution for coping with unanticipated events, which have largely been neglected by conventional approaches.

The theoretical foundations of EID (Burns & Hajdukiewicz, 2004; Vicente, 1999; Vicente & Rasmussen, 1992) support the argument that the framework could contribute to this benefit in two ways. First, the information content and structure identified by the Work Domain Analysis are explicitly selected to support operators in coping with all events, including unanticipated ones. In contrast, conventional approaches only explicitly identify information requirements of anticipated events. While all of these design approaches could effectively support monitoring for anticipated events (as suggested by the negligible performance difference between display types in the Detection phase of Procedure-guided scenarios (see Figure 9), the information content and structure in Ecological displays should better support operators in coping with unanticipated events. Second, the graphical forms in Ecological displays followed the Skills, Rules and Knowledge taxonomy, which served as an overarching framework to guide design towards high compatibility with human information processing (for all levels of cognitive controls). On the other hand, conventional approaches usually contain specific, rather than overall, design heuristics and principles (e.g., O'Hara & Brown, 2002) to ensure compatibility with information processing. Thus, Ecological displays could communicate process information more effectively to operators than displays based on conventional approaches. This advantage would also be most prominent for information related to knowledge-based rather than rule-based decision making when common monitoring strategies do not apply.

The performance advantage of the Ecological displays, however, did not persist in the Mitigation phase of Knowledge-based scenarios, as predicted by the framework and observed in previous empirical studies. We postulate four related factors contributing to the diminished performance difference between display types in the Mitigation phase. First, operators were engaged in a greater mixture of tasks during the Mitigation than Detection phases. During the Detection phase, operators monitored process deviations and began problem solving. On the other hand, during the Mitigation phase, operators constructed intervention plans and executed control actions in addition to problem solving tasks. During the Mitigation phase, operators could have engaged some tasks involving rule-based decision-making even in Knowledge-based scenarios, such as executing control actions according to their planned solutions. In other words, the Mitigation phases inherently included tasks besides problem solving even in Knowledge-based scenarios. In effect, the unique support for problem solving provided by the Ecological displays may not be as relevant during Mitigation in comparison to the Detection phase.

The intervention nature of the Mitigation phase also relates to the remaining postulated factors. The second factor is that intervention may be more robust to interface effects as operator responses would rely on multiple skills and resources (e.g., trainings and procedures) as well as representation aides. Therefore, performance advantages induced by any one type of displays would be less discernable during the Mitigation phase due to reduced reliance on representation aides. The third factor is that the Traditional and Advanced displays could contain features particularly effective for intervention. Task-based and user-centered approaches typically emphasize efficiency and precision in executing control actions. Furthermore, the Ecological displays retained the same methods of interaction as the Traditional and Advanced displays, inhibiting a full assessment of the EID framework in supporting intervention. Fourth, enhanced support for other aspects of work, such as intervention as emphasized by the Traditional and Advanced displays, could lead to greater cognitive resources allocated to problem solving, thereby minimizing performance differences across display types. From this perspective, interface designers might regard task-based and user-centered approaches as complementary techniques to be integrated with the ecological approach (Burns & Hajdukiewicz, 2004; Jamieson et al., 2007). While these factors are plausible explanations for the lack of observed performance differences between the display types in the Mitigation phase, the results of this study prompt further empirical examination that explicitly compares visualization features contained in displays based on EID and other approaches.

4.3 Limitations

Several limitations to the findings of the study warrant consideration. First, the Ecological displays employed in this study are, in fact, a hybrid Ecological-Traditional interface. The hybrid nature is evident in that: a) the scope of the Ecological displays was limited to the secondary side, b) the overview display in the Ecological display condition was the same as the Traditional one, and c) the interaction to control/operate the simulator was consistent across all display conditions. All of these limitations were a direct consequence of the limited resources available for this study. Still, the reliance on a hybrid implementation raises the question of compatibility between the two display types that has not been investigated in the open literature. Given that the full plant must be in operation during the experiment, crews in the Ecological display condition used different types of displays to control the primary and secondary sides of the plant. In the Ecological display condition, crews used the large screen display in the Traditional display condition because an ecological version was not developed. This choice was influenced by the scope of the research program that excluded design work for the displays of reactor operators (i.e., the primary side), who also used the large screen display for monitoring. Furthermore, the interaction style was devised for the Traditional and Advanced displays, but was also used by participants in the Ecological display condition. This decision was governed by the availability of training time, which was estimated to be sufficient for only one interaction style. For all of these reasons, intervention may have been more challenging in the Ecological display condition.

It is worth noting that, although a hybrid implementation is not ideal from an experimental perspective, it is actually quite representative of industry practice. In our experience, industry tends to adopt novel interface design techniques in phases, testing new concepts in limited operations while retaining the full suite of traditional controls. Thus, the benefits for the Ecological interface demonstrated in this experiment are likely to be conservative estimates. A comparison of displays that included displays for the primary side and large screen displays, and an interaction scheme based on EID, would provide a more accurate assessment of the merits of the ecological approach.

A final limitation is the limited training provided to operators in using the Ecological displays. Operators were generally more familiar with both the Traditional and Advanced displays, which are similar to the hard-wired panel in the control room of the nuclear plant being simulated. In an experiment spanning several days, it is not possible to endow operators with the level of familiarity in a novel display that they have attained with displays that are either highly similar (i.e., Traditional) or substantially similar (i.e., Advanced) to those employed in their workplace. Thus, to observe superior performance with the Ecological displays in any condition compared to the others is rather remarkable from a training perspective. Again, it is likely that the benefits for ecological displays shown in this experiment are conservative estimates of the full effect of EID.

4.4 Contribution

This empirical study marks the beginning of EID validation in the nuclear domain. The findings replicate some of those in the only other EID study that is representative of operations in the process control domain (Jamieson, 2007). Taken together these studies demonstrate that the benefits of ecological interfaces observed in laboratory settings can scale up to industry applications. The present study also demonstrated that hybrid implementation of ecological and conventional interfaces did not appear to hinder performance relative to (uniformly implemented) conventional interfaces. This provides reassurance that the common industrial strategy of adopting new visualization techniques in an evolutionary manner is a viable avenue for adopting EID.

4.5 Future Work

Validation depends on convergent support from a series of empirical studies. Subsequent studies must address several unattended issues. The scope of future assessments must be expanded to include the primary side and other operator support tools (e.g., large screen displays). Studies employing alternative performance measures (e.g., system efficiency) are also needed to obtain both convergent and discriminant validity. A complete set of human performance measures would also illustrate the particular facets of work best supported by EID. A more extensive set of scenarios is also needed to explore the consistency of support provided by ecological displays in other operating modes (e.g., start-up, shut-down, and re-fuelling). As recommended by Burns & Hajdukiewicz (2004) and investigated by Jamieson (2007; Jamieson et al., 2007), our findings suggest that integrating other approaches into the EID framework to explicitly provide procedural supports through ecological interfaces may result in efficient and robust interfaces which may not be achieved with any one design techniques. Thus, future studies in HAMMLAB should explore the integration of design techniques.

5. CONCLUSION

Our research objective is to collect design, verification and validation evidence to assess the merits of EID in the nuclear domain. Welch et al. (2007) and Lau et al. (in review) presents the design and verification evidence indicating that the EID framework can lead to visualization features and verification criteria that are valuable for supporting and ensuring effective monitoring during both anticipated and unanticipated events. Together with the work of Skraaning et al. (2007) and Burns et al. (in review), this report presents our empirical evaluation of ecological displays in a setting representative of a nuclear power plant control room with professional operators. The results on operator task performance (documented in this report) support the conclusion that ecological displays could provide a marked advantage for monitoring for unanticipated events over other conventional displays while other performance differences between the interfaces are relatively negligible. Furthermore, ecological displays seem to achieve this performance advantage without any workload increments. This conclusion marks a promising beginning of EID validation in the nuclear domain. These results are particularly encouraging because EID appears to be a design solution for coping with unanticipated events, which have largely been neglected by conventional approaches. This study, therefore, contribute to the ongoing effort to improve human-system interaction in the nuclear industry.

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7. APPENDIX A: PLOTTING CONFIDENCE INTERVALS FOR WITHIN SUBJECT DESIGNS

The confidence intervals for all the effect plots in this report were gtraphed using the method proposed by Cosineau (2007). These confidence intervals cannot be generated by a standard function of common statistic software applications. This appendix presents the graphing procedure for ploting such confidence intervals.

7.1 Observed Means/ANOVA

Below is the procedure for graphing effect plots with confidence intervals for observed means. That is, the data points do not need any further adjustment. Refer to the next section for plotting data points that need covariate adjustment.

(1) Save the data into a **new** file.

(2) Calculate the grand mean of data.

(3) Organize the data into 'wide format' (i.e., every row represents a unique participant and every column represents a unique experimental condition) as needed in performing repeated-measures ANOVA.

To use the formating function in Statistica, go to ->"Data" -> "Unstacking/Stacking".

(4) Calculate means of each row (i.e., each participant) and column (i.e., each experimental condition).

In Statistica, this can be done by highlighting the relevant data and right click to select -> "Statistics of Block Data" ->"Block Column" (or "Block Rows") -> "Means" (see, Figure 11). Omit irrelevant columns and rows (e.g., crew)

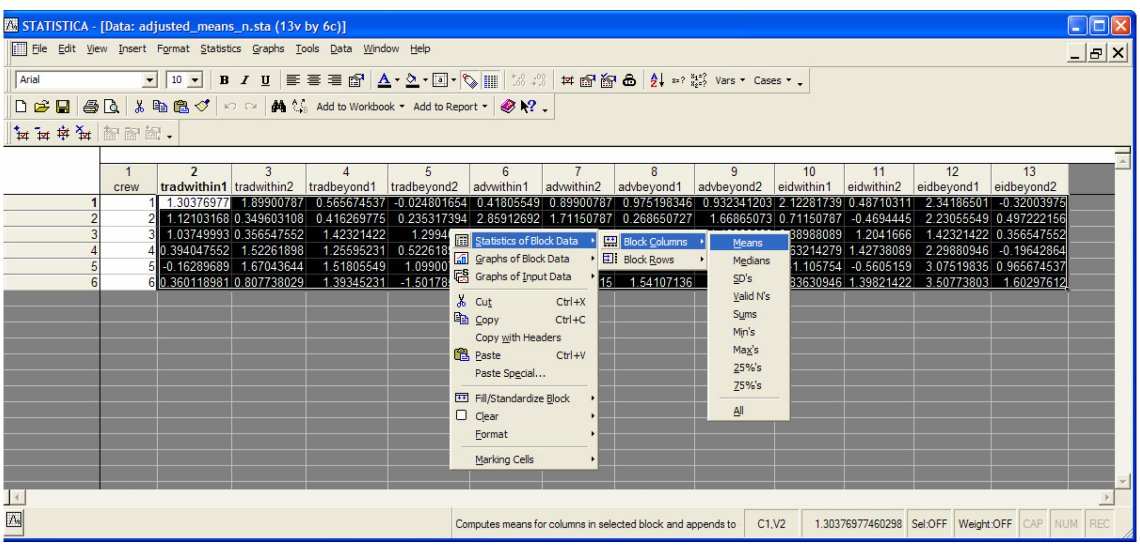

Figure 11: Calculating means by column and row in Statistica.

(5) Add a new column. The values for this column should be calculated automatically by inputing a formula in the fomula box (see, green box of Figure 12). The formula should correspond to:

= Grand Mean – Row (participant) Mean +

Column (value of the participant for that condition) (1)

Note: The Grand Mean and Column Mean are *constants* in the formula, whereas, the Row Mean is a *variable*.

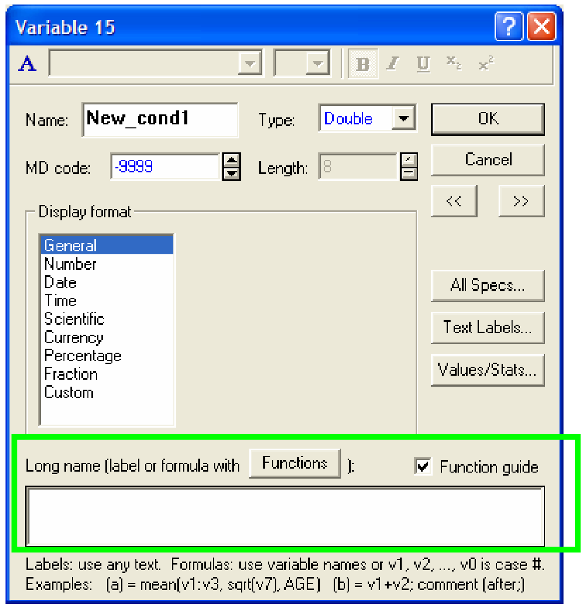

Figure 12: Dialog box when adding a new variable in Statistica.

(6) Repeat step (4) until there is a new column for each column containing the original data. (i.e., for every unqiue conditions). Omit the column containing row means.

Note: The Grand Mean is a *constant* in the formula for *all* new columns. Column Mean is a *constant* in the formula for *each* new column. Row Mean is a *variable* in the formula for all new columns.

(7) Delete the row(s) containing the column means. Delete the columns containing the original data and row means.

(8) Reorganize data in the long format (i.e., one column for every treatment and one column for the measurements).

(9) Plot the data using standard graphing functions in any standard statistic software applications. In Statistica, go to ->"Statistics"->"Basic Statistics and Tables", and select "Descriptive statistics" (see Figure 13). Then, select the "Categ. plots" tab and click on the "Categorized means (interaction) plots" (see, green box of Figure 14).

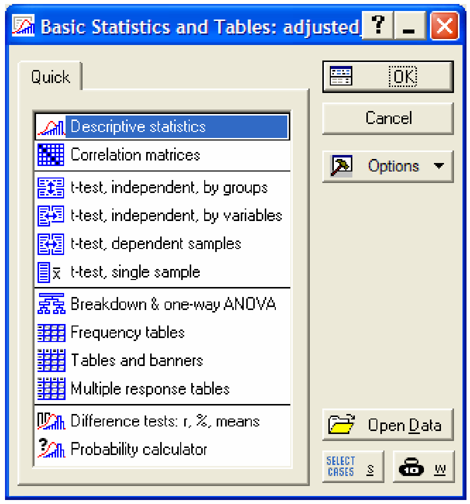

Figure 13: Dialog box of Basic Statistics and Tables in Statistica.

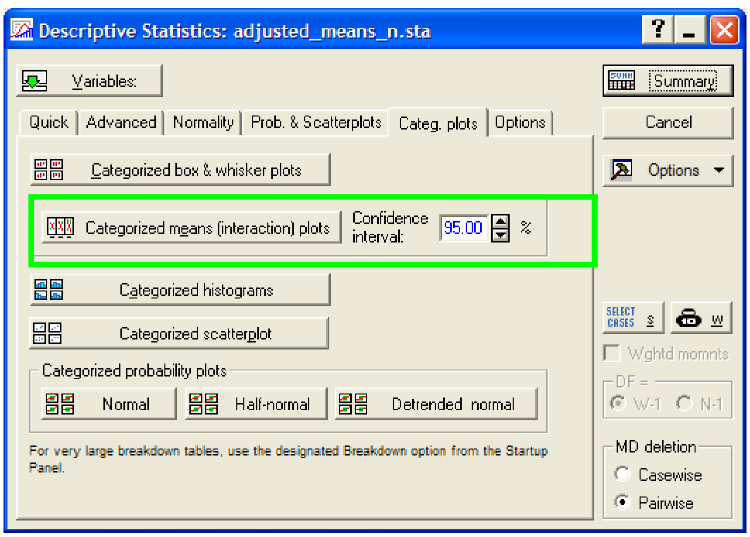

Figure 14: "Categ. plots" tab of a "Descriptive Statistics" Diaglog Box in Statistica.

7.2 Adjusted Means/ANCOVA

In order to generate effect plots of ANCOVA using the method proposed by Cosineau (2007), the data points must first be adjusted by one or more covariates. The adjusted means, which could be then used with the graphing procedure, should be accessible in the statistic software after performing an ANCOVA on the original data set.

In Statistica, the means adjusted for the covariate can be retrieved by clicking on "Least square means" from "Means" tab of the "GLM Results" dialog box after running an ANCOVA (see Figure 15). Copy the data set into a new file and perform the procedure in section 7.1 above.

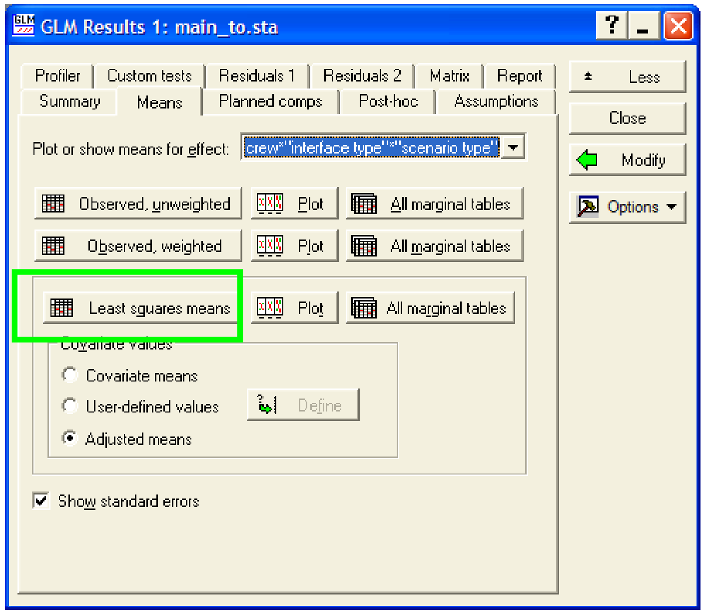

Figure 15: "Mean" tab of a "GLM Results" Diaglog Box

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