DEVELOPMENT OF THE DELPHI DISPLAY CONCEPT FOR ALTERNATIVE EXPLANATIONS DECISION MAKING SUPPORT

Charles Weaver, John Gwynne, and Mark F. St. John
Pacific Science & Engineering Group
9180 Brown Deer Road
San Diego, CA 92121
charlesweaver@pacific-science.com; JohnGwynne@pacific-science.com;
markst.john@pacific-science.com

ABSTRACT

Human operators of advanced technology systems, such as nuclear power, command and control, and deepwater oil drilling, must be able to evaluate and respond to a wide array of operational anomalies. Unfortunately, these circumstances are often complex and ambiguous, complicating decision making tasks. One common decision making error, called confirmation bias, occurs when decision makers prematurely focus on one explanation instead of systematically considering all plausible alternative explanations that could equally well account for an operational anomaly (Nickerson, 1998) [1].

The Delphi display is designed to counteract decision makers' tendencies towards confirmation bias and to encourage them to consider all plausible explanations, including high risk explanations, they might otherwise overlook. An initial Delphi display prototype was designed to help identify the underlying cause of operational anomalies in the complex, high-consequence technology of deepwater drilling. This prototype decision aid incorporates major indicators related to operational anomalies and presents corresponding plausible explanations for each indicator, ranging from high-risk system-critical explanations to lower-risk but still significant events. The Delphi display incorporates several innovative features to help decision makers detect and monitor operational anomalies and view the relationships among indicators and their associated plausible explanations.

Preliminary evaluations of an early prototype Delphi display for detecting kicks in deepwater oil drilling operations have been promising. Moreover, the methodology used to design and develop the Delphi display can be readily generalized to numerous other operational contexts that require humans to make system-critical decisions. To illustrate, an initial Delphi display design for nuclear power plant control is described.

Key Words: decision making, confirmation bias, alternative explanations, visualization

1 INTRODUCTION

High-consequence technologies, such as nuclear power, command and control, and deepwater oil drilling, can provide much-needed products that benefit all segments of modern society. However, hazards and risks associated with these technologies can pose significant dangers not only to workers in these fields, but to the larger society as well. Evaluations of operational incidents in high-consequence technologies often find that human error has played a role in the failure to prevent an incident or to respond in an effective and timely manner after an incident has begun. A detailed understanding of the complex human-system interactions that occur in advanced technology systems is needed to develop interventions that can reduce the likelihood of operational mishaps and enhance the overall safety of both industry workers and the general public.

For example, a detailed analysis of well control incidents in deepwater oil drilling found numerous human factors issues involved in the performance of deepwater drilling tasks (St. John, 2015, 2016) [2][3]. Decision making was found to be sub-optimal across a wide variety of well control incidents. One phenomenon found in a number of incidents was a tendency to focus on a single explanation during a loss of well control event instead of considering all the plausible alternative explanations that could be responsible for causing that event. This cognitive tendency, known as confirmation bias, is in fact commonplace in applied decision making situations. It occurs when people preferentially seek information that supports their preconceived explanations or beliefs about a situation, while they simultaneously ignore or downplay information that supports equally plausible alternative explanations.

To overcome this tendency for confirmation bias, rig crews need help in generating alternative explanations, especially high risk explanations, as well as help in systematically and objectively evaluating evidence that supports or disconfirms various explanations as a well control event unfolds over time. The innovative software decision aid described in this paper was designed for this purpose.

While deepwater oil drilling provided the context for the initial development of this decision aid, the underlying design concepts and principles that guided its development can be applied equally well to numerous other contexts, including the nuclear power industry. This paper will first discuss the development of this decision aid for deepwater oil drilling decision making, highlighting its major features and capabilities. Next, its relevance to decision making in nuclear power plant control rooms will be illustrated by an example that involves a steam generator tube rupture accident in a pressurized water reactor (PWR) light water reactor (LWR) plant.

2 DECISION AID DEVELOPMENT

2.1 Indicator-Explanation Framework

A set of five well control incidents where confirmation bias clearly occurred were selected for detailed analysis. A detailed timeline was developed for each incident to capture important indicators of the well's status as they became available during the incidents. An indicator is a well status parameter that is monitored during drilling operations. These indicators provided differential diagnostic value for identifying the underlying causes of loss of well control events. Additionally, whenever possible, the explanations favored by the rig crew at each moment during the incident were identified.

Next, an analytic framework was developed to map the indicators of well status to all likely explanations, regardless of whether they were considered by a rig crew. These explanations included high risk events, such as a "kick" due to an unexpected influx of oil or gas into the well from the rock formation, and lower risk events, such as rig sway from crane movements or sea state. First, the list of indicators was ordered to reflect the most important and influential indicators in loss of well control events. Similarly, the alternative explanations for each type of well control event was ordered from highest to lowest risk. Second, each loss of well control indicator was mapped to each alternative explanation that could be affected by that indicator. This mapping resulted in a matrix that clearly illustrated the functional relationships between indicators and explanations.

A decision aid was then developed that incorporated these relationships in a user interface that is easy to understand and use.

2.2 Delphi Display: Features and Functionality

An initial concept for displaying the relationship among well control indicators and their related alternative explanations was designed based on human factors user-centered design principles. These principles consider the capabilities and limitations of the people who interact with a system to ensure the system is designed to be consistent with those capabilities and limitations. The prototype decision aid for deepwater drilling, called Delphi, is designed to help decision makers identify the underlying causes of loss of well control events in deepwater drilling. This prototype incorporates several design features to help decision makers detect and correctly interpret critical operational anomalies, thereby reducing the likelihood that confirmation bias will influence their decisions. These features are related to the layout of the Delphi display; the use of highlighting to emphasize key aspects of the display, such as when indicators and plausible explanations change so decision makers can track developments on the display; and the ability of decision makers to test hypotheses about the operational anomaly being experienced.

2.2.1 Display layout

As shown in Figure 1, the well status indicators are presented in the top half of the display, and the alternative explanations are presented in the bottom half. Because some indicators were deemed to be more diagnostic than others by the oil industry subject matter experts (SMEs), the indicators were grouped into two categories, primary and secondary with the primary ones bolded and starting on the top left hand side. The alternative explanations were categorized by the type of event. Geologic events included gas and oil kicks. These are high risk events, and they were placed in the middle of the display and colored red to ensure they were highly visible to decision makers at all times. Drilling equipment events included pit transfers, in which drilling fluids are moved about the rig, and heavy in annulus, which describes the distribution of fluids in the well. Environmental and rig events included sea state and sway caused by the movement of a crane on the rig. These lower risk events were placed lower in the display and colored gray.

2.2.2 Highlighting to focus attention

In Figure 1, the indicators that apply to a hypothetical well control event are shown in cyan; the non-applicable indicators are gray. The alternative explanations that fit with those indicators are highlighted. Only one indicator supporting an explanation is needed to highlight that explanation. Explanations that are ruled out by the active indicators are grayed-out. By displaying the alternative explanations that apply to a given set of indicators, the Delphi display alleviates confirmation bias by helping decision makers a) quickly see the full range of explanations that fit a given situation and set of indicators, and b) understand how these additional explanations are supported by the indicators. In this way, the Delphi display encourages decision makers to consider multiple plausible explanations, including high risk explanations, they might otherwise overlook. This design helps avoid confirmation bias, and supports a more thorough evaluation of the underlying causes of well control anomalies.

The cyan highlighting also indicates and draws attention to which well control indicators have experienced a significant recent change in their value, thereby providing the decision maker with change awareness for that indicator. The thresholds for highlighting indicators are typically lower than the thresholds for general, rig-level alarms because the highlighting is used to support situation monitoring rather than indicate danger, per se. For example, a change in rate of penetration (ROP) of drilling will not trigger an alarm on conventional rig displays, but it will highlight the Delphi display indicator for ROP change. Cyan highlighting persists for 10 minutes, at which time it changes to white highlighting, indicating aging information. After 30 minutes, the white highlighting reverts to gray, signifying that the indicator has not changed significantly during that time. The progression from cyan to white to gray therefore provides the decision maker with information about the temporal history of indicator onsets and persistence.

2.2.3 Hypothesis testing

An important and unique feature of the Delphi display is its ability to support active hypothesis testing by the decision maker. This capability enables the decision maker to explore alternative scenarios that may not currently apply, but which may become relevant as a system anomaly evolves over time. Hypothesis testing is enabled by an interactive functionality built into the Delphi display that enables decision makers to view the functional relationships between indicators and explanations. Any explanation can be selected by clicking on that explanation. The selected explanation and its associated indicators will show temporary pink corner highlights. In Figure 1, for example, the Formation Ballooning explanation has been selected. The indicators mapped to this explanation also show a pink corner highlight. Thus, a decision maker can

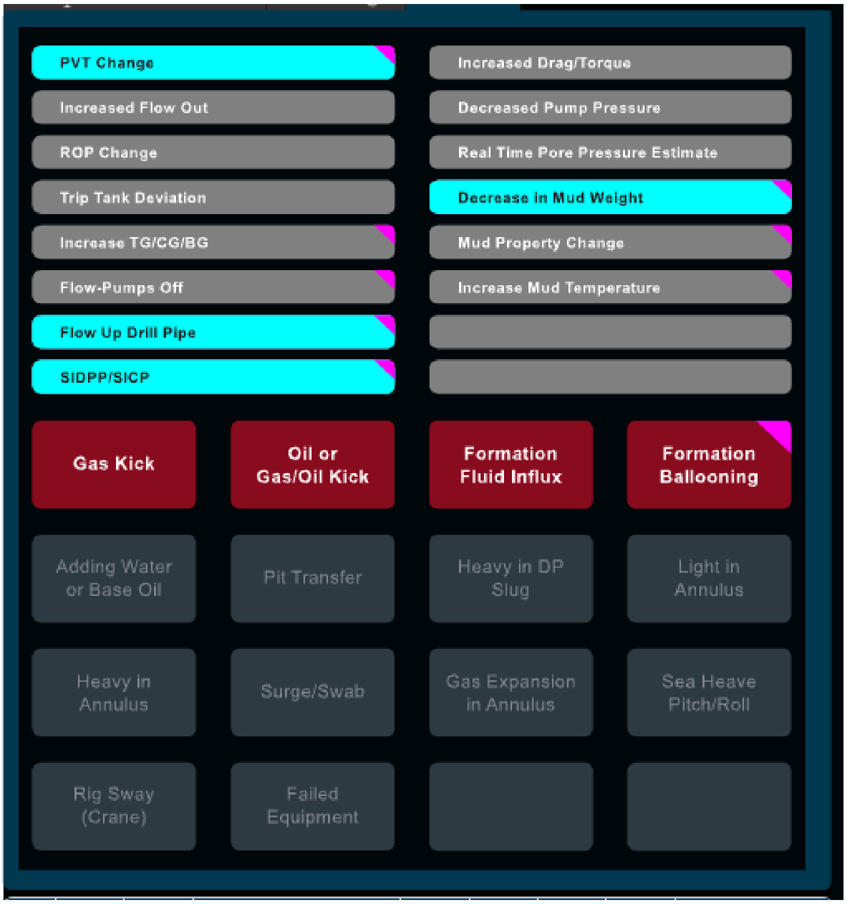

Figure 1. Prototype Delphi design for evaluating alternative explanations in deepwater drilling loss of well control events.

explore the relationships that may exist among the indicators and explanations for a given anomaly. This interaction also provides a way to identify other indicators that might be checked or monitored to support or rule out one or more alternative explanations. In an analogous way, an indicator can also be selected to show which set of explanations are plausible for the selected indicator.

2.3 Prototyping and Formative Usability Testing

A set of prototype displays was developed to evaluate the initial Delphi display concept. These prototypes provided views of the Delphi display during the progression of several loss of well control scenarios, based on incident data collected from official U.S. Government investigation reports. The Delphi display was evaluated by two subject matter experts in well control. These evaluations consisted of first evaluating the adequacy of display content and format for conveying the relationships among indicators and explanations, and then walking through three pre-selected well control scenarios to observe how the Delphi display responded to changes in well control indicators. The utility and design of the Delphi display was discussed after each scenario. Overall, the Delphi display was deemed to be very useful for considering the full range of alternative explanations that applied to a given loss of well control scenario, which in turn facilitated the accurate diagnosis of well control anomalies.

Additionally, the SMEs suggested several improvements to the Delphi design including addressing additional phases of drilling operations, availability of customizable indicators and explanations, ability to accommodate system mode changes (e.g., starting or stopping drilling and pumping), highlighting of newly activated and deactivated explanations, ready access to recent significant events (e.g., the last flow check), and the use of a pop-up alert for urgent operational recommendations to decision makers (e.g., shut in the well).

The prototype Delphi displays were also analyzed using a computational model of display clutter (Rosenholtz, 2007) [4]. Clutter measures the background noise in a visual display. A central component of the model is to look for transitions in color and brightness on a display. These crisp transitions help important details stand out clearly from the rest of the display when they represent important information. However, these crisp transitions create clutter when they represent irrelevant details in a display. Figure 2 provides an example of a clutter analysis of a prototype Delphi display, with brighter spots showing areas of higher clutter. The results of the analysis were used to further improve the display by reducing clutter around important display elements, enabling them to be more easily and quickly located.

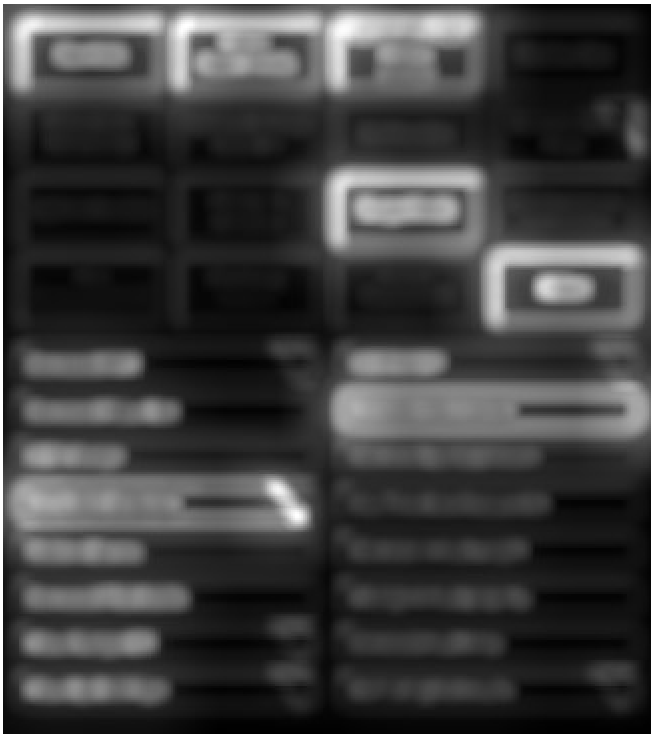

Figure 2. Clutter analysis of a prototype Delphi display.

3 NUCLEAR APPLICATION

An initial Delphi display prototype appropriate for use in the nuclear power domain was developed to demonstrate the general applicability of the underlying design concepts. A preliminary set of indicators and explanations was developed for a pressurized water reactor (PWR) plant. The indicators included fluid properties, power levels, and containment properties, while the explanations covered high level classes of transients with the more critical transients listed first. Figure 3 shows an initial design prototype for this display. The five most important and influential indicators are presented first in the list and are bolded; the less critical indicators appear next and are not bolded. The three highest risk explanations are colored red and are ordered from highest to lowest risk (i.e., Anticipated Transients Without Scram (ATWS) > Loss of Coolant Accident (LOCA) > Small Break LOCA).

The example scenario depicted in Figure 3 shows how a Delphi display would appear for a hypothetical steam generator tube rupture (SGTR) accident with a low flow rate. The display shows a time well after the pressurizer level began to decrease (highlighted and aged to white), but before the reactor coolant temperature begins to decrease (not highlighted). A recent decrease in both the pressurizer pressure and volume control tank levels are indicated by cyan highlighting. Five explanations that fit these cyan and white indicators are highlighted.

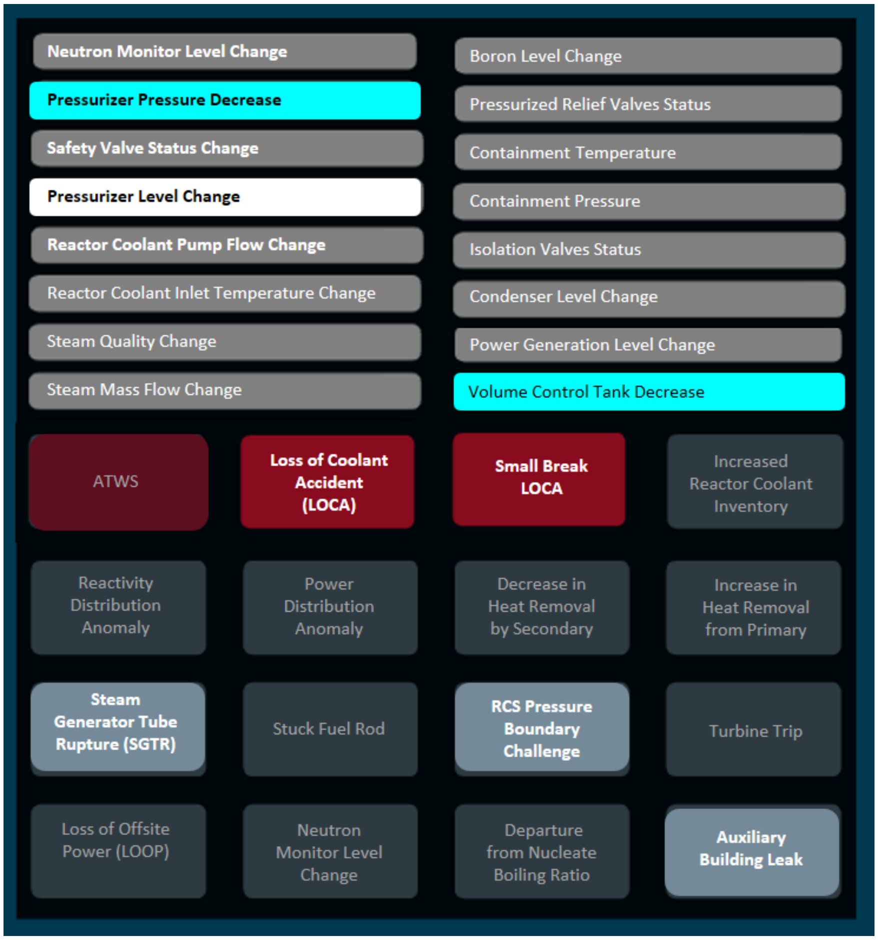

Figure 3. Delphi display concept for pressurized water reactor (PWR) operation.

Decision makers might choose an initial explanation of a leak in the auxiliary building (e.g., the auxiliary feedwater line), due to it being a more common incident, and not consider a higher risk less frequent SGTR (Marsh, 1980; MacDonald, 1996) [5][6]. However, by using information presented by the Delphi display, decision makers can be guided toward the full set of explanations, especially the higher risks ones, and thereby avoid the trap of confirmation bias. The general applicability of the Delphi design process bodes well for its use in the nuclear industry, as illustrated by this hypothetical example of a complex and ambiguous event.

Several additional activities are required in the development of a prototype Delphi display for this application. The indicators and alternative explanations need to be verified and validated with nuclear industry SMEs to ensure that no important factors have been omitted. The mapping of the indicators to the explanations should be reviewed by SMEs who are not involved in the initial mapping to ensure that mapping is accurate and complete. To be most operationally effective, the Delphi display should be tailored to meet the requirements of a specific plant design and operating mode with a plant training simulator.

4 CONCLUSIONS

Confirmation bias can hamper sound decision making and thereby increase the risks faced by workers in high-consequence industries such as deepwater drilling and nuclear power. However, decision aiding tools that could help to minimize confirmation bias to date have received little attention by industry. This paper reports the initial efforts to develop a decision aid specifically designed to reduce the frequency and severity of confirmation bias and improve worker safety in hazardous industries. These efforts have obtained promising preliminary results, suggesting that further development is warranted. The Delphi display demonstrated that it can help decision makers to generate alternative explanations that are relevant to the circumstances encountered in real-world industrial operations. Specifically, decision makers frequently need help in considering high-risk explanations and evaluating evidence that either supports or disconfirms alternative explanations.

The Delphi display can effectively address problems that arise due to delayed and inadequate responses to operational anomalies by increasing decision makers' situation awareness, risk assessment, and risk communication. It accomplishes this by systematically presenting information that decision makers can use to improve their situation awareness, risk assessment, and risk communication. Its ability to focus the decision maker's attention on high-risk explanations by increasing their salience is an effective way to make them high priority considerations. Likewise, its ability to support hypothesis testing enables decision makers to readily explore current and developing relationships among a host of indicators and their associated explanations.

The application of the Delphi display design process to a hypothetical SGTR accident described in this paper indicates the Delphi display can be readily extended to decision making in the nuclear power industry. Presenting the multiple relevant explanations for a SGTR accident supports the operators in a complicated decision making task and helps them avoid prematurely focusing on a single explanation. This is done by providing information they can use to systematically consider all plausible alternative explanations that might account for an operational anomaly.

Finally, the development of training curricula is another potential application area for the Delphi display. These curricula would teach decision makers how to view and interpret the displays, but more importantly, would impart the cognitive skills supported by the Delphi display, including situation awareness, comparative evaluation of alternative explanations, team communication, and accurate differential diagnosis of system anomalies. The Delphi display would also help train the mapping between indicators and the full range of related explanations. Both critical thinking skills and knowledge of the mapping of system indicators to plausible explanations should transfer readily to operational settings, even in the absence of the Delphi display in the work environment.

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