2017

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Recommended Citation

Strobhar, D. (2017). Petrochemical plant console operator workload: the issues. *H-Workload 2017: The first international symposium on human mental workload*, Dublin Institute of Technology, Dublin, Ireland, June 28-30. doi:10.21427/D7192C isbn:9781900454637

Petrochemical Plant Console Operator Workload – The Issues

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Abstract. The console operators of certain petrochemical processes must maintain high levels of performance during process upsets or endanger personnel safety and the environment. Mismanagement of an upset can result in explosions, fires, and the release of hazardous chemicals to the environment. The change in workload from steady state to upset operation is significant, with alarms and control changes that are of an order of magnitude. This paper describes the state of console activity in process plants, particularly the increase with key upsets. Quantitative data on the nature of the console operator's position, its workload during normal operation, and the requirements during upsets is shown. The goal is to spark discussion and potential investigation as to how to quantify the mental workload associated with the physical workload.

Keywords: console operator workload, mental workload, distributed control systems, process plant upsets

1 Introduction

Every day across the world, thousands of operators are monitoring and controlling process units that have flammable and/or toxic material operating at high pressures and temperatures. Equipment failures and unexpected changes in material are managed with no adverse impact on anyone. However, occasionally they are not managed well, and the results can be fatalities and severe environmental impact. The US Chemical Safety and Hazardous Investigation Board details the impacts of such an event at what was then BP's Refinery in Texas City (TX) in 2005, where 15 fatalities and 180 injuries resulted from a release of hydrocarbons and subsequent explosion that damaged houses almost one mile away [1]. The Occupational Safety and Health Administration set standards and regulations designed to see that these types of events are kept to a minimum [2]. However, like commercial aviation accidents, even one is too many.

The potential impact of operator performance on process plant operation has gained attention over the years. The American Petroleum Institute determined that 28% of the 88 incidents that occurred between 1959 and 1978 were the result of human error [3]. A study by Chadwell, et al, had a value of 47% for process plant incidents that were the result of human error [4]. Several operating companies formed the Abnormal Situation Management consortium in 1994 to develop tools to improve response to process plant upsets [5]. In 2007, the Center for Operator Performance was established to fund research on methods to improve the performance of process plant operators [6].

The goal of this paper is to identify some of the issues in console operator workload with the hope of spurring research into an area. While a search of the publications by the Human Factors and Ergonomics society reveals research on mental workload for nuclear power plant operators [7][8][9], a similar query for refinery operators yielded no results. While nuclear power plants have more potential for catastrophic impact on the environment, refineries have more complicated processes and considerable potential for safety and environmental impact. The physical actions that an operator takes, both under normal and abnormal operating conditions, is far better known than the mental workload demands. This paper describes what is currently known regarding console operator workload with the hope of sparking discussion and investigation into development of mental workload assessment tools and methodologies.

The data presented in this paper is the product of 30 years of analyses (time-and-motion, cognitive task analysis) performed on over 1000 processing units across North America by the author. Data on alarm, control, and display change rates is the product of direct observation and categorization of operator actions for multiple four-hour blocks of time, with an example of the raw data in Figure 1. The observations encompass over 300 console operating positions and over 2500 hours of operation. The data reflects refineries, chemical plants, pipelines, and production facilities.

INITIATION TIME	Display Name	Monitor	Control Change	Alarm
7:57:45	t4 bttms	8		
7:58:14	h3	8		
7:58:23	d2 desalter	8		
7:58:50	t5 overview	8		
7:59:07	t5 hvgo	8		
7:59:42	t5 tgo	8		
8:00:27	t5 bttms	8		
8:00:49	alarm sum	6		1
8:01:25	d200 desalter	8		
8:01:43	t200 pumparound	8		
8:02:03	t200 pumparound	8	1	
8:02:31	lab samples	8		

Fig. 1. Example of Data Collection for Console Operator Activity

2 Nature of the Work

Control of a process unit entails oversight of thousands of data points and hundreds of control points. A process unit is a series of vessels and equipment that alters the nature of the incoming material to create higher value material. This change can be either through separation of components and/or rearrangement of molecules. Often the use of heat, pressure, and catalysts are required. Pumps, compressors, and valves are used to modulate and move the material. The levels, pressures, temperatures, and flow of this material are recorded at various locations in the process. Manipulation of the rotating equipment and valves enables the operator to maintain these variables within ranges specified by the engineers.

Operators have three basic pieces of information from the process. The first piece of information is the value of the process variable, the temperature, flow, pressure, or level. An operator will typically have a thousand of these variables that they can examine, with some operators having 5000 or more. The second piece of information is the desired setpoint for those variables that need to be controlled. This is a much smaller subset, 150-500 of the several thousand variables being measured. These are the points at which an operator can intervene and change the process, usually by opening or closing a valve. The third and final piece of information is the position of the valve that is needed or demanded to reach the desired setpoint. This value can and will change to keep the process variable at the desired setpoint.

The information is provided to the operator via a control system. The current systems consist of 3-12 monitors on which the process operator can display some subset of the thousands of variables for which they are responsible. The operator can change the setpoint on the control variables via these displays and put a valve in manual to open or close it. Any of the thousands of points can generate an alarm on either passing a threshold or changing state (i.e., on/off), which will generate a color change and flashing of the point on the display. A list of all alarms is provided in some manner.

3 Normal Operation

The average console operator spends the vast majority of time on the tasks in Table 1, with approximately one-half of the time engaging in a directly observable activity. The other half of the time, no physical activity can be seen, with the hope that the time is spent thinking, processing, or transitioning between tasks. As the nature of the job comprises a large number of tasks per hour (over 25), they have only a short time from when one task ends to when the next begins (on average one minute).

Table 1. Console Operator Average Time on Task

Task	Time on Task
Administrative	13%
Inspection	12%
Laboratory	1%
Maintenance	2%
Misc/Add. Duties	2%
Operational	21%
Total	**52%**
Tasks/hour	26.2
Mean time between tasks	1.1
Communications/hour	10.7
Alarms/hour	6.4
Control Changes/hour	6.3
Display Changes/hour	22.6

The demands of the process are captured in the time spent on operational tasks. This is largely communications, alarms, and control moves. The average operator will see about six alarms, make six control changes, and have ten communications in the average hour. Twenty-some display changes are needed to carry this out. The degree of mental workload for this routine operation is unknown, along with the spare capacity available to handle upsets.

4 Upset Workload

Every now and then, something in the process will break or change unexpectedly. Equipment and instrumentation occasionally fail. Materials used in the process are not of the necessary or expected quality. The result is a process upset.

Successful response to a process upset entails three key steps: (1) detection, (2) identification, and (3) response [10]. The operator must detect that a failure has occurred. Although this is often easy when hundreds of alarms actuate within minutes, it can also be subtle and not readily apparent at first. Next comes troubleshooting the cause and development and implementation of a course of action. Generally, one of three paths will be taken: (1) return to the prior operating condition, (2) change to a new operating mode, or (3) a partial or complete shutdown of the unit.

The impact of failures on the operator can be seen in Figure 2. One failure is a carryover of water from a desalter on a crude unit into a fired furnace. The other two events are a trip of a gas compressor and shutdown of a fired heater used to heat the process material. Malfunctions increased alarms by a factor of five. Control changes increased three to five times. Display changes tripled. Certainly, mental workload increased, but by how much? That is unknown.

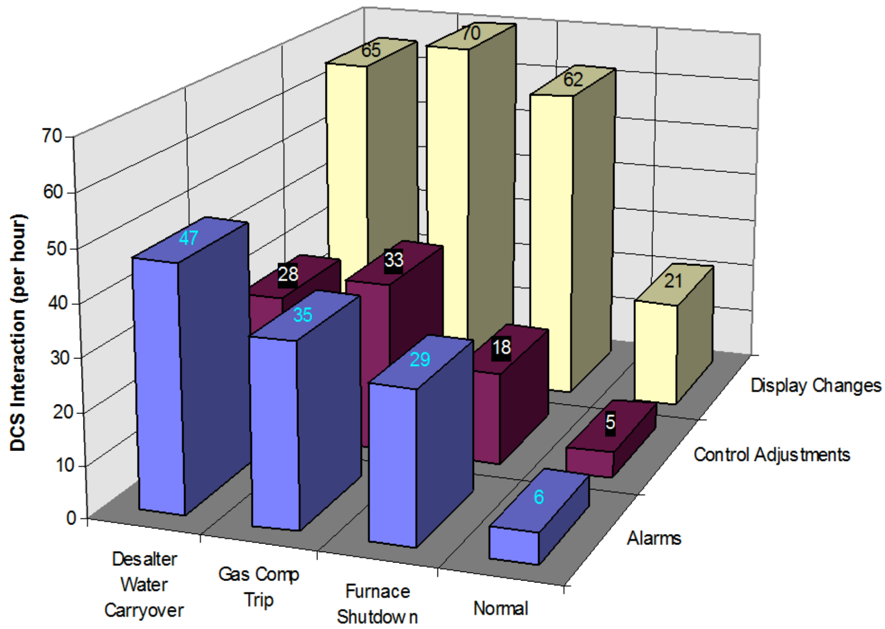

Fig. 2. Impact of Upsets

Use of hourly averages understates the demands placed upon the console operator. Most of the demands are at the beginning of the event. Figure 3 shows alarm actuations in five-minute increments for a heater malfunction. Here we see five-minute periods with over 300 alarms actuating. The alarms and workload ebb and flow over the several hours of the event. How does the mental workload change during this period? That currently is not known, but the answer could potentially have significant impact.

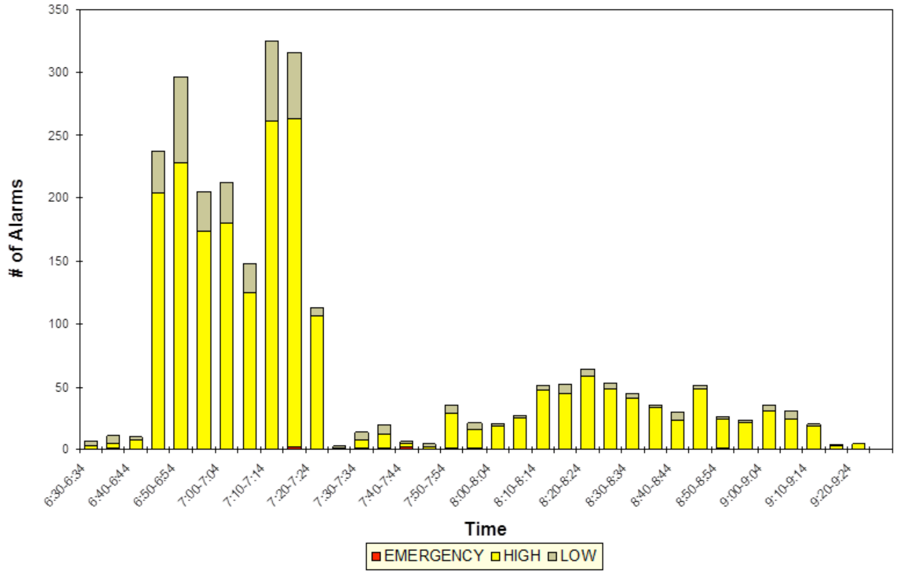

Fig. 3. Alarms after Heater Malfunction

5 The Challenge

Plants are constantly looking for ways to improve their performance. While one goal is to prevent upsets from occurring, another goal is to enable those upsets to be managed when they occur. Plants have and will continue to make headway to make progress in improved upset management. Industry groups have published standards or guidelines on various aspects of operator performance, such as the Engineering Equipment and Materials Users Association's "Alarm Systems: A guide to design, management, and procurement" [11], the International Society of Automation's ISA18.2 "Management of Alarm Systems for the Process Industries" [12] and the International Society of Automation's "Human Machine Interfaces for Process Automation Systems" [13].

What is unknown with all these improvements is the degree to which they reduce mental workload demands and improve plant safety. The process industries need tools to assess the impact of these changes to further the safety and environmental performance of their units. The process industries need to be able to ensure that their console operators have the mental workload capacity to manage process upsets when they occur.

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