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# Operator performance as a function of alarm rate and interface design


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## KEY WORDS

Operator performance, alarm rates, alarm displays


## ABSTRACT


Alarm rate limits have been suggested by various industry groups (ISA, EEMUA) with little empirical data to support those limits. The Center for Operator Performance funded research into the effects of different alarm rates and interface designs on operator performance. A laboratory study was conducted using a pipeline simulator with five different alarm actuation rates and two different interface designs. The subjects were students from Louisiana State University. Statistically significant effects ($p<.001$) were found with alarm rates, while an interaction was discovered between alarm rates and interface design. Follow-up research is underway using process plant and pipeline operators with the alarm rates over a longer period.

## BACKGROUND

Alarms and messages from the process control system is a basic form of automation that enhances overall system safety and performance. The alarms and messages prompt operators to take action if either the process has gone outside desired operating limits or if new action is required to proceed with the batch. As with automation in general, the result is fewer operators are needed to monitor and control process equipment. This raises the question of how many alarms and messages can an operator effectively attend? At what point will the process performance potentially become unsafe or inefficient if too many alarms/messages are generated?

Until now little empirical data was available on the impact of alarm/message rate on operator performance. The Engineering Equipment and Materials Users Association stated that more than one alarm per minute is "likely to be unacceptable" for long term steady operation, with one alarm every two minutes "likely to be over-demanding."[1] Although the values "result from an analysis of operating experience in a number of industries," the underlying data are not provided and it is unclear what is meant by "long term." The International Society of Automation (ISA, previously Instrument Society of America) stated in its Alarm Management Standard that an average of two alarms in ten minutes is the "Maximum Manageable."[2] While also stating that this value is "approximate," it also states the value is based upon operator abilities without reference to how the "maximum" was derived. Often estimates on the limits of human performance are based upon folk psychology, what to the outsider seems to be a reasonable level that an operator can handle. However, folk psychology notoriously underestimates human capabilities. Expert estimates of how many cruise missiles a single operator could handle underestimated the number by over factors of three.[3] Clearly data are needed.

The need for data on all aspects of operator performance was the basis for the creation of the Center for Operator Performance (COP), based at Wright State University in Dayton, Ohio. A collaboration of operating companies (BP, Chevron, Flint Hills/Koch, Marathon, NOVA Chemical, SUNCOR Energy) and DCS suppliers (ABB, Emerson), the COP funds research to answer questions needed to enhance operator performance. The COP is open to any company, with operating companies deciding what research is needed. One of the initial projects was examining the impact of different alarm rates on operator performance. In order to demonstrate manipulating different variables in one experiment, different methods of alarm presentation were utilized. Dr. Craig Harvey of Louisiana State University was selected to conduct the experiment due to his familiarity with alarm issues in process control.

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[1] "Alarm Systems: A Guide to Design, Management, and Procurement," Engineering Equipment and Materials Users Association, Publication No. 191, 1999, pp 105.

[2] "ISA SP18.2 - Management of Alarm Systems for the Process Industries," International Society of Automation, Research Park Triangle, NC. 2009. pp70-71

[3] Cummings, M.L. and Guerlain, S. "Developing Operator Capacity Estimates for Supervisory Control of Autonomous Vehicles," Human Factors, Vol. 49, No. 1, Feb. 2007, pp.1-15

 

## EXPERIMENT

Isolating the impact of alarms and displays on operator performance requires control of any extraneous variables. That way, differences in performance can be attributed alone to the variables being manipulated. Statistical analyses can then estimate the probability that any differences in performance were due to random variability, or chance. Five different alarm rates were selected for evaluation with two different methods of presentation. Subjects were randomly subjected to the ten treatment conditions of ten minutes each, as in Figure 1. The Chronological presentation displayed alarms by time of actuation with color used to show one of three priorities. Categorical presentation grouped the alarms by priority. Alarms were evenly distributed across the three priority levels, although low priority alarms were not audible. The result is the lowest priorities were more typical of operator messages than alarms.

| | Treatment Condition | |
|---|---|---|
| Alarms per 10 minutes | Chronological | Categorical |
| 1 | 10 min | 10 min |
| 2 | 10 min | 10 min |
| 5 | 10 min | 10 min |
| 10 | 10 min | 10 min |
| 20 | 10 min | 10 min |

*Figure 1 - Experimental Conditions*

A simulator of a pipeline was used to conduct the experiment. Pipelines are semi-batch operations. While the goal is to not stop the flow, different tenders of material (batches) are present throughout the pipeline and must be delivered. Four different performance measures were captured: (1) time to acknowledge, (2) time to initiate corrective action, (3) accuracy of response, and (4) percentage of abnormal situations handled. All alarms the subjects received had defined responses, so the experimenters could assess if the subject did all of the responses and in the desired order. The subjects were LSU students, who received training on how to operate the pipeline simulator and were tested to ensure proficiency. By having all subjects do all ten experimental conditions, differences in subject ability were balanced.

## RESULTS

The mean reaction time, time from when the alarm activated until the participant handled the alarm [time to initiate corrective action], is shown in Figure 2. As can quickly be seen, performance is about the same for the four lowest alarm rates. Only at 20 alarms in 10 minutes (hereafter referred to as 2010 condition) does performance begin to degrade. Of equal importance is that while performance degraded at the 2010 condition, the degradation was not equal. Performance was far slower with the chronological display than the categorical display. The results for the other performance measure exhibited this same pattern.

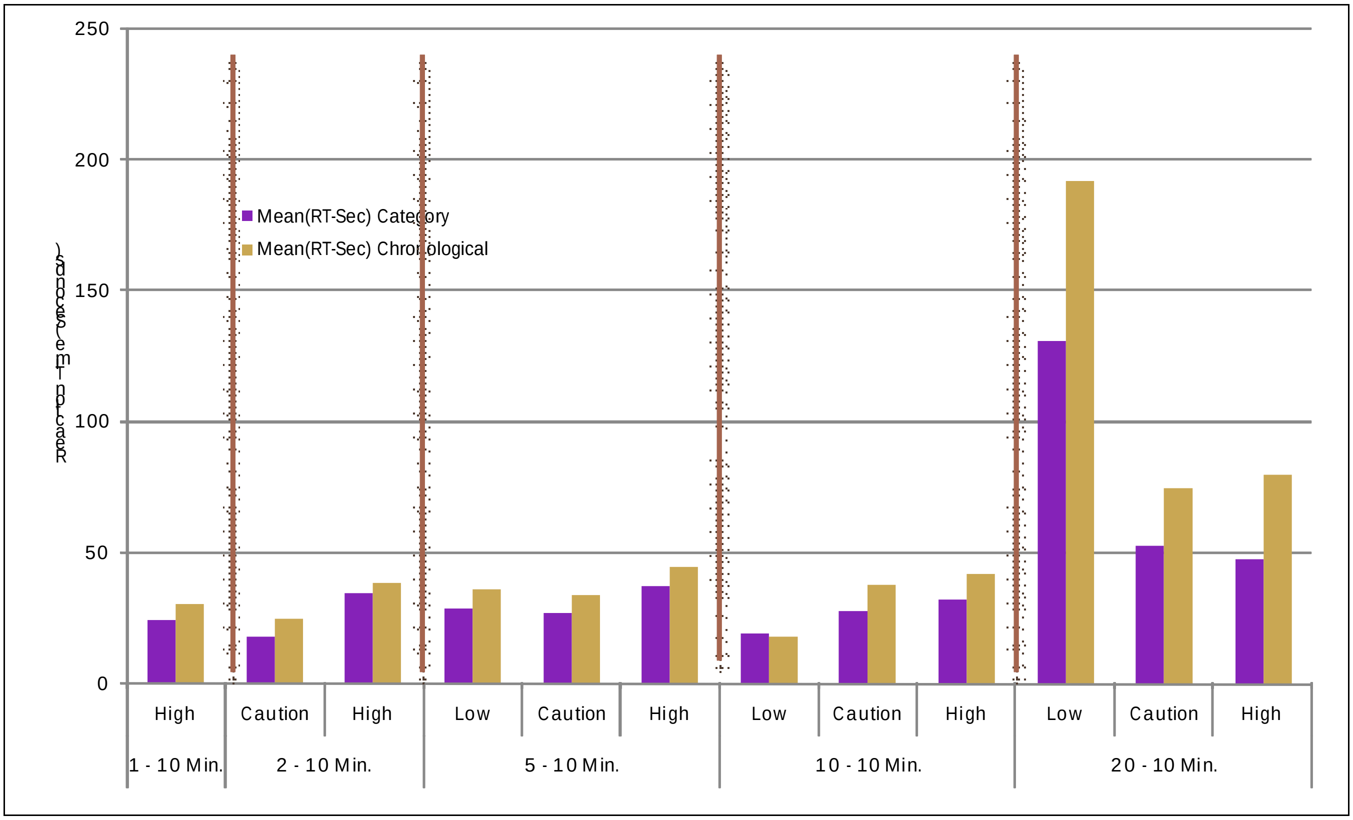


*Figure 2 - Subject Mean Reaction Time*

The goal of experimental design is to allow statistical analysis of the variation in results. An analysis of variance (ANOVA) was conducted, with a summary of the results in Figure 3. The key statistic is the last column, which is the probability that the results are due to chance. Alarm rate has a significant impact on performance, with a less than 0.0001 probability that the results obtained were due to chance. Presentation mode (Categorical/Chronological) alone does not have a significant impact on performance, with a greater than 5% probability that the differences were due to chance. However, there is an interaction between the variables of alarm rate and presentation method. That is the last row with a less than 0.0153 probability that the better performance with the categorical displays in the 2010 condition was due to chance.

| **Source** | **ANOVA Results** | | | |
|---|---|---|---|---|
| | **DF** | **Sum of Squares** | **F Ratio** | **Prob > F** |
| Alarm Rate | 4 | 2137765.9 | 47.9078 | **<.0001** |
| Presentation mode (Categorical/Chronological) | 1 | 34194.5 | 3.0652 | 0.0801 |
| Alarm Rate* Presentation mode (Categorical/Chronological) | 4 | 137439.4 | 3.0800 | **0.0153** |

*Figure 3 - Analysis of Variance Results*

# IMPLICATIONS

The results of this study have both specific and global implications. The specific issues relate to interface design and staffing of process plants. The global issues relate to how display design is approached and how standards are set for operator performance/interface issues.

Some process plants are staffing their console positions based largely upon alarm rates. The results of this study would indicate that such plants are using more operators than might be needed. If the rates that a plant is using are from EEMUA, then they are likely too conservative. This study demonstrates that operators can handle an alarm rate higher than the EEMUA values. In addition, if the plant were to display alarms grouped by priority, than an operator could potentially have a span of control 40% greater than if the alarms are arranged chronologically. More important than the $300,000 per year cost of a post position is the potentially negative performance impact of having an under-loaded operator. Low workload can be as detrimental to performance as high workload. If using an overly conservative alarm metric as the basis for staffing results in too low workload, then a degradation of operator performance and an increase in operator errors may result.

The global implications from this study are significant.

- First, the study points to the ability to quantify operator performance issues in process control. “Best guesses” and “consensus limits” need not be the basis of standards dealing with the process operator. Research can be conducted to provide realistic and defensible data.
- Second, the study points out the problems in relying on operator preference for display design. While many operators prefer chronological formats and say they perform as well, this study points out that such an assertion is valid only for low alarm rates. Methods exist to provide that which enhances operator performance, not just operator preference.
- Third, the study shows the interaction between human performance variables, such as interface design and staffing. A better interface enables operators to handle “more” than an inferior interface, thus requiring fewer operators. Analysis of the operator-process system can move beyond simplistic loop counts for staffing and address the multivariable nature of operator performance.

It is important to remember that the purpose of this study was to establish what impact alarms had on operator performance, hoping to establish a threshold or limit. The intent and results should NOT be interpreted as setting a desired or preferred alarm rate. However, understanding the limit of alarm/message rate is critical to ensuring safe and efficient operation, similar to knowing mechanical limits of the process equipment.

The membership of the Center for Operator Performance quickly saw the potential power in the results and the inherent limitations. Altering how alarms are displayed could improve operator performance in high alarm situations by over 40%. However, the experiment was done with LSU students handling alarms for only 10 minutes at a time. Therefore, a follow on study is underway which utilizes actual pipeline and refinery operators who will be exposed to the alarm rates for a longer time period.

 