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Measurements of Response Times of Human Operators in Control Rooms

Preliminary Results

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1. Introduction

A research programme is being run at Riso concerning the control room layout and the communication between operator and instrumentation in large industrial plants. The aim is to find appropriate ways of presenting information so that a quick and reliable communication can take place.

An important information channel from the plant to the operator is the warning or alarm system by means of which the plant signals when a predetermined plant parameter level has been transgressed.

The warning signal initiates operator action, and the pattern of warning signals combined with the measured data and the general plant operating status are the basis for the operator's identification of his task.

For studies of the role of the information carried by the warning signals in different plant conditions and operator tasks, a recording system was installed at the research reactor DR3. The system records the time of arrival and clearance of warning signals and the patterns of warning signals related to these moments.

These records will enable us to analyse warning signal information in relation to different plant conditions, plant subsystems and operator tasks and to correlate warning conditions to plant operating history, maintenance procedures etc. This analysis will be carried out in co-operation with the reactor plant operating staff.

The system also offers the possibility to analyse operator response times, time spent to remedy abnormal conditions and time distributions of similar events.

Operator response times have been studied by Green et al. UKAEA (1) using equipment called HORATIO (Human Operator Response Analyzer and Timer for Infrequent Occurrences).

This equipment uses an alarm lamp which lights at random intervals and a reset button. Response times between lamp indication and reset action was recorded and showed a log normal distribution with mean response times around 2. 5 sec.

While this equipment was additional to the control room instrumentation, our equipment (called HAMLET), works on the instrumentation itself and thus adds no extra equipment to the control console.

It gives a good opportunity to collect response time information comparable to the UKAEA data, and the present report gives a preliminary analysis of the gross response times found. When more data are available, a detailed analysis relating data to plant conditions and operator working conditions will be worked out.

The response times can be analysed in many ways from the recorded data. Thus the possible influence of the number of alarms or type of alarms can be considered. The effects of the time of the day or the shift Pe -riod can be analysed. So it is the aim of the experiment to describe important factors in the operator's communication with an alarm console in order to gain a basis for a quantitative design and safety evaluation of such equipment. Two aspects of operation are considered, one concerning the safety aspects for the plant and one concerning the daily operation, where the instrumentation is a communication medium and a protective system for less important auxiliary system in the plant.

2. Alarms and Incident Recording

The test equipment is installed in the control room at the DR 3 reactor. This reactor is supervised by some 80 alarm circuits connected to transducers either in the reactor circuits or in the different experiments. The alarms are displayed in front of the operator on a large panel which contains the names o,-L-the different alarms.

Whenever a new alarm comes up, a warning bell rings. This bell can be reset with a push button in front of the operator. Another push button 1 0 cm away from the bell reset button is used to reset the alarm panel, i. e. to extinguish those alarm lamps for which the alarm condition has disappeared. Thus the alarm lamps remain lighted (even if the alarm condition has disappeared) until the alarm panel reset button is activated.

A normal sequence of events is bell ringing, bell resetting and later alarm panel resetting. These events are named 0, P and Q events respectively. The times for these events are printed on tape giving hour, minutes, seconds and tenths of seconds for the event.

I 00 msec after a P and Q event the alarm status is scanned and punched out.

3. Preliminary Analysis

A computer programme was developed to analyse time differences between either 0 and P events and 0 and Q events or P and Q events, and to prepare a frequency distribution of response times. A number of conditions concerning number of alarms, types of alarms and times can be set up so that event times are only registered when these conditions are fulfilled.

The frequency of events during normal operation is:

0 and P events:	2.06 per hour (based on 1142 events)
Q events:	2.61 per hour (based on 1444 events)

showing that there are several alarm panel resets for each new alarm and bell reset.

The number of alarms active when a bell reset is made, is distributed as follows:

1 alarm active:	43%
2 alarms active:	35%
3 alarms active:	13%
4 alarms active:	3%
More than 4 active:	6%

A single run of the data for a distribution between times of P and Q events shows a distribution which deviates from the log normal distribution. It appears that there is a large number of very long time intervals. Only those Q's that are adjacent to a P are counted, and repeated Q's are disregarded.

4. Discussion of Results

This first analysis was made without a priori knowledge of the operator habits and ways of acknowledging alarms. It appears that the reset of the alarm bell seems independent of the alarm status, but perhaps dependent on the tiredness of the operator. A nice log normal distribution shows up in accordance with other findings (1), but with slightly different response times (means of 3. 6 sec against I sec found elsewhere). This can be due to different distances for reset buttons, or due to the special significance of the HORATIO signal to the operator.

The dependence on time of the day and shift period could be further investigated when more data are available.

The response time to reset of the alarm panel does not show a log normal distribution, and a further investigation is needed. We have been informed that the operator does not reset some alarms because he knows that they will be present for some time. This may be the reason why so many long response times are present.

Another hypothesis may be that the operator tries to reset the alarms very quickly in order to handle spurious alarms. This may especially be so when many alarms come up simultaneously. By rejecting the special alarms which are not reset and examining the response times as functions of number of alarms a log normal distribution may appear, giving the possibility of intercomparison and significance test.

Furthermore, when more data are available the response time for specially chosen alarms could be derived, thus giving information on reset of important and unimportant alarms.

(1) A. E. Green, Safety Assessment of Automatic and Manual Protective Systems for Reactors. A. H. S. B. (S) R 172. (1969).

(2) A. Hald, Statistiske metoder. Den private Ingeniørfond (1948).

APPENDIX

Response times as measured in this experiment tend to show a log normal distribution, i. e. the log of the response times is normally distributed. This means that calculations of moments and tests for significance should be made for the log times. An example shows the calculations:

Interval times (sec)	log times	Interval middle	Number of events a_i	Interval number w_i	w_i^2	$(w_i+1)^2$
0. 20-0. 25	-0. 7--0. 6	-0. 65	2	0	0	1
0. 25-0. 31	-0. 6--0. 5	-0. 55	2	1	1	4
0. 31-0. 40	-0. 5--0. 4	-0. 45	5	2	4	9
0. 40-0. 50	-0. 4--0. 3	-0. 35	3	3	9	16
0. 50-0. 63	-0. 3--0. 2	-0. 25	0	4	16	25
0. 63-0. 79	-0. 2--0. 1	-0. 15	2	5	25	36
0. 79-1. 00	-0. 1--0	-0. 05	5	6	36	49
1. 00-1. 26	-0. ---0. 1	-0. 05	11	7	49	64
1. 26-1. 60	-0. 1--0. 2	+0. 15	51	8	64	81
1. 60-2. 00	-0. 2--0. 3	+0. 25	78	9	81	100
2. 00-2. 50	-0. 3--0. 4	+0. 35	168	10	100	121
2. 50-3. 16	-0. 4--0. 5	+0. 45	248	11	121	144
3. 16-3. 98	-0. 5--0. 6	+0. 55	236	12	144	169
3. 98-5. 02	-0. 6--0. 7	+0. 65	165	13	169	196
5. 02-6. 30	-0. 7--0. 8	+0. 75	97	14	196	225
6. 30-7. 90	-0. 8--0. 9	+0. 85	43	15	225	256
7. 90-10. 00	-0. 9--1. 0	+0. 95	12	16	256	289
10. 00-12. 80	-1. 0--1. 0	+1. 05	6	17	289	324
12. 80-15. 90	-1. 1--1. 2	+1. 15	5	18	324	361
15. 90-19. 90	-1. 2--1. 3	+1. 25	2	19	361	400
19. 90-15. 20	-1. 3--1. 4	+1. 35	0	20	400	441
25. 20-31. 60	-1. 4--1. 5	+1. 45	0	21	441	484
31. 60-39. 80	-1. 5--1. 6	+1. 55	1	22	484	529
39. 80-50. 10	-1. 6--1. 7	+1. 65	0	23	529	576
Total n			1142			

Total sum $S = \sum n_i w_i$ 13080

S^2/n = 149813

Total sum control $s_c = \sum n_i (1+w_i)$ 14222

S_c^2/n = 177114

Sum of squares SK = $\sum n_i w_i^2$ 155396

Sum of squares control $\sum n_i (1+w_i^2)$ 182698

Sum of squared deviations $SAK = SK - s^2/n$ 5583 5584

Variance of w $s_w^2 = SAK/(n-1) = 4.8940$

The frequency distribution for times between bell ringing and bell reset is calculated for the total number of events and in some special cases, namely as a function of the number of alarms active when the bell is reset and in the beginning and at the end of the shift period. In the latter case the two first and the two last hours of the shift are chosen.

In all cases the distribution turns out to be log normal, i.e. the log of the response times is normally distributed with the following parameters:

	Log times		Times	
	Mean	Deviation	Mean	Deviation
Total	0.4954	0.221	3.6 sec	1.6 sec
First part of shift	0.4193	0.232	3.0 sec	1.7 sec
Last part of shift	0.5289	0.216	3.8 sec	1.6 sec
1 alarm active	0.4904	0.211	3.5 sec	1.6 sec
2 alarms active	0.5064	0.214	3.6 sec	1.6 sec
3 alarms active	0.5094	0.258	3.7 sec	1.8 sec
4 alarms active	0.3947*	0.312	3.1 sec	2.1 sec
More than 4 active	0.2660*	0.388	2.7 sec	2.4 sec

*Crude statistical analysis

A slight increase in mean time during the shift can be detected. This is just significant, and a repetition should be made when more data have been accumulated.

The response times as a function of the number of alarms active shows no effect, except for 4 or more alarms which may be due to bad statistics.

Diviation of w $s_w = 2.2122$

Mean of w $\overline{w} = S/n = 11.4535$

The calculation of w is started from $\alpha = -0.65$

With a group interval $\beta = 0.1$

The mean of the log times is therefore

$$\log \xi = \beta + \overline{w} = -0.65 + 0.1 \cdot 11.4535 = 0.49535$$

$$\sigma = \beta\ s_w = 0.1 \cdot 2.2122 = 0.22122$$

The median and mean of the times is given by

Median: $\log x = \log\xi = 0.49535$; i.e. $x = 3.13$ sec

Mean: $\log x = \log\xi + 1.1513 \cdot \sigma^2$; i.e. $x = 3.55$ sec.

Deviation: $\log x = \sigma = 0.22122$; i.e. $x = 1.66$ sec.

A test for significance for two sets of results consists of a test for equal means and equal deviations.

The two sets with n_1 and n_2 measurements are supposed to have the moments (ξ_1, σ_1) and (ξ_2, σ_2).

A first test of $\sigma_1 = \sigma_2$ is made by calculating

$$V^2 = s_1^2 / s_2^2$$

which is a F-distribution with $f_1 = n_1 - 1$ and $f_2 = n_2 - 1$ degrees of freedom

If $\sigma_1 = \sigma_2$, we test $\xi_1 = \xi_2$ by calculating

$$t = \frac{\bar{x}_1 \quad \bar{x}_2}{s \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

When $\bar{x}_1$ and $\bar{x}_2$ are the means and s a total standard deviation

$$s = \frac{(n_1 - 1) s_1^2 + (n_2 - 1) s_2^2}{n_1 + n_2 - 2}$$

t is then t-distributed with $f = n_1 + n_2 - 2$ degrees of freedom.

When $S_1^2 \neq S_2^2$ a simple test of $\xi_1 = \xi_2$ cannot be performed according to (2).

As an example a test of the total distribution of response times and the distribution for the two test hours of a shift period is made.

Total: $\xi_1 = 0.4954$ $\sigma_1 = 0.221$ $n_1 = 1142$

First part of shift: $\xi_2 = 0.4193$ $\sigma_2 = 0.232$ $n_2 = 111$

$v^2 = s_1^2 / s_2^2 = 1.102$, $f_1 = 1141$ and $f_2 = 110$

$$t = \frac{0.0761}{0.222 \cdot 0.0994} = 3.44$$

The F table shows a $v^2 = 1.24$ on the 5% level, which means no significant difference in standard deviation. The t table shows a $t = 2.58$ on the 1% level, so the greater t found indicates a significant difference in means.