Multitasking and Interruption Management in Control Room Operator Work During Simulated Accidents

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Abstract. Our everyday life is full of interruptions, which cause problems in different situations. Therefore, efficient management of interruptions is a natural part of our daily activity, and we humans are experts at managing task switching and interruptions. Efficient management of interruptions is required in many tasks and domains such as in health care, aviation, car driving and office work. This paper focusses on control room (CR) operator work in nuclear power plants. CR operators have to manage interruptions in various plant states, and sometimes interruptions cause problems in their work. This paper is divided into two major parts: the first part is a short literature review of effects of multitasking and interruptions in work settings; the second part presents some experimental results of multitasking and interruption management during simulated accidents. Some suggestions are given to improve interruption and multitasking management in safety-critical domains.

Keywords: Multitasking · Interruption management · Nuclear power plant · Control room operator

1 Introduction

Interruptions are an inherent aspect of many work environments, such as emergency services [1]. Recently, about one-third of respondents of the European Survey on Living and Working Conditions answered that they were interrupted several times a day [2]. The rate of interruptions has also drastically increased during the last decades. A survey conducted in Germany showed that the rate of interruptions has doubled in the past 20 years, and according to this study, interruptions at work are evaluated among the most important causes of stress at work [3].

At the same time, multitasking is growing steadily, and it has become a natural and normal condition in many work domains so that it is more and more difficult to recognize that you are multitasking at work. According to [4], employees are facing an increased demand for multitasking, and when they have to perform multiple tasks at the same time, it may be even difficult to determine what the primary and secondary tasks are and what interrupts and disturbs what.

D. Harris (Ed.): EPCE 2016, LNAI 9736, pp. 301–310, 2016.
DOI: 10.1007/978-3-319-40030-3_30

But multitasking and frequent interruptions at work are not necessarily considered as a problem or a nuisance: sometimes employees may even be proud of their skill of performing several tasks simultaneously, and multitasking may also be a breath of fresh air compared with normal work [5]. Also, interruptions and multitasking have in some contexts been described as something that makes the work more attractive [6].

1.1 Effects of Multitasking and Interruptions

One of the main goals in studying interruptions and multitasking is to acquire knowledge of their effects on employees and their performance. Apparently, interruptions have both positive and negative effects. They affect task completion time and quality of work, and they also exert influence on cognition, emotions, workload and well-being in general.

Interruptions are not basically either bad or good, and, as suggested above, sometimes interruptions may have positive effects on performance [6–8]. In fact, interruptions may provide valuable task-related information just at the moment it is needed [8]. For example, it is feasible to send an alert to a colleague, if he/she is about to carry out an error [7].

According to the systemic view, workers must constantly trade-off between potentially positive and negative effects of interruptions, rather than avoiding interruptions altogether. The cost of interruption can be defined as a subjective measure of the price people are ready to pay to remain undisturbed while working in a particular task [9]. Hollnagel's [10] functional resonance model (FRAM), according to which both accidents and successes are caused by unexpected combinations of normal behavioral variability, can quite well explain how interruptions may have both positive and negative effects.

Even though moderate levels of multitasking may even increase performance, most existing research suggests that interruptions and excessive multitasking have harmful effects on performance and well-being [4]. For example, according to [9], multitasking is less efficient and more complicated than single tasking.

Overall, interruptions increase the task completion time, hamper decision making, and easily lead to slips, lapses and mistakes [11]. The main factors of interruption effects on quantitative task performance are increased memory load and task similarity [12]. One of the main problems of interruptions is that their harmful effects can last long after the interruption has ceased [13].

Interruptions also cause loss of time [14]. The task completion time of the task with interruption increases by two transition time intervals: interruption lag and resumption lag [15]. The 'interruption lag' is the switching time from the primary task to the secondary interrupting task, and the 'resumption lag' is the return time from the secondary task back to the primary task [15]. Both the accomplishment of the primary interrupted and secondary interrupting task may be delayed. According to [16], ill-placed interruptions can increase task performance time, especially because of increases in resumption time. In a situation in which the interruptions are nested and accumulated, the duration of the delay will further increase because of the additional cognitive burden [4].

In safety-critical domains, an important question is to show whether there is a causal link between interruptions and errors. For example, evidence for a relation between interruptions and medical errors are still quite weak [7]. According to [7], this is apparently caused by deficit methodological approaches, not because there would be evidence of absence of evidence.

Interruptions have shown to cause all kinds of cognitive effects, such as memory loss and less accurate recall of information [17], detrimental effects on decision making [18] and breaks in concentration [15]. When interrupted, people quite easily forget what they were initially doing. Successful prospective memory performance requires that we are able to recall something at a specific point of time in the future which is more demanding that simple remembering a particular fact [5]. And if your attention is constantly wandering from one information source to another, you may not be able to build a complete and coherent view of the status of the matter, when recalling the interrupted task [19].

Weigl et al. found that interruptions were significantly correlated with employees' workload over and above the contribution of other variables [8]. Kalich and Aebersold have also shown that interruptions had a negative effect on workload [20]. Frequent interruptions were associated with increased frustration in Weigl et al.'s study, and interruptions by colleagues had a strongest association to workload [8]. Cumulative interruptions may have an even more detrimental effect on workload [4]. In addition, interruptions under periods of high workload may have a more detrimental effect on task performance, since people take longer to resume the suspended tasks during these periods [16].

In addition to cognitive costs, interruptions may also cause emotional costs [21]. Interruptions had a negative effect on emotion and well-being [20, 22], and interruptions can increase feelings of stress and frustration [23], as proposed above.

1.2 Effects of Sensory Distractions

An ongoing task has to stop in case of interruption, but an ongoing task can continue in a distraction condition [12]. Irrelevant speech and noise are one of the most important causes of distraction in many work domains. Irrelevant sound has shown to disturb concentration and impair task performance. According to several experimental studies, most of the participants suffer from irrelevant sounds, even though there are notable and consistent individual differences in susceptibility to noise effects [24]. The effect has been shown to result in an average increase of errors of up to 30 % [24].

Abrupt changes in successive auditory signals have shown to be the main cause of the distraction effect [25], but the intensity of the auditory signal does not seem to have a clear effect on the irrelevant sound effect [24, 26]. A work environment, in which there is continuous background chatter, is less distracting than an environment in which several distinct speech events are present at the same time [24]. Irrelevant sound effects do not seem to diminish with time and repeated exposure to the disturbing sounds [27].

Background sounds, such as auditory warnings and irrelevant radio messages that occur in a random and unpredictable fashion, have also shown to impair concentration and increase errors [28, 29]. This effect may be caused by attentional capture effect in which the irrelevant sound diverts attention away from the primary task [30]. As suggested by Boehm-Davis and Remington [31], the fact that even subtle alarms and warning signals can distract attention may explain why workers find it frustrating and stressful to process alarms, even though they know that the alarm signals can be ignored.

1.3 Interruptions, Distractions and Multitasking in Nuclear Domain

To our knowledge, there is very little research on multitasking and the impact of interruptions in the nuclear domain, even though, based on a French survey, Griffon-Fouco and Ghertman [32] proposed that interruptions of job performance have shown to explain over 15 % of all nuclear power plant shutdowns.

Alarms can easily distract operators in CR environments. Alarms accompanied by auditory signals easily attract the operator's attention, and thus, interrupt his/her primary task execution. Many of the presented alarms are useless, and the operators consider them as annoying [33]. Mumaw et al. [33] proposed that a majority of alarm messages in the nuclear power plant (NPP) control room (CR) do not require operator action at all.

Carvalho et al. have investigated in many studies operator work and team communication in the main CR of a NPP [34, 35]. They have found that the operators have to cope with many irrelevant alarms in different operational modes which they cannot ignore without violating against emergency operating procedures [34, 35]. For example, it was found several times in their study that the operators turned off the alarm buzzer in order to muffle the disturbing sounds, even though it is forbidden to do that [35]. It was also observed that phone calls can be very distracting, if the operators are busy and have too many tasks to do in an incident situation [35]. On the other hand, internal communication with the crew played an important role to solve technical problems, and individual comments and questions of the crew members are not considered distracting [34, 35].

Apparently, multitasking and task interruptions are common in 'normal' operational conditions, and operators have also told that the amount of multitasking has clearly increased during recent years (personal communication). In simulated accident situations operators focus on accident management, and therefore interruptions that halt the execution of the primary task are infrequent. However, all kinds of distractions that disturb operators' concentration on their duties are frequent, and it would be, therefore, justifiable to study their effect on operator performance.

2 Methods

We have observed NPP main CR operators' work in order to investigate the effects of interruptions and task switching in simulated accident management situations and the management of multiple parallel tasks. In the analysis, we have utilized video data from operators' head-mounted cameras and a general-view camera. Head-mounted camera videos show at a crude level to what information the operator is paying his/her attention, and therefore they provide a mean to identify the task he/she is performing. We have analysed video data from loss-of-coolant accident (LOCA) simulation runs. Each observed operating crew consisted of three operators (reactor operator, turbine operator and shift supervisor).

In a separate study, we were interested in CR operators' personal opinions regarding interruptions encountered and frustration caused by these interruptions. Twenty-two operators responded to a questionnaire in connection with a simulator test in a Finnish NPP.

3 Results

3.1 Interruptions in Simulated Accidents

We studied interruptions in an NPP CR in a demanding operational situation by analysing data from a simulated accident scenario. A loss of coolant accident was simulated together with a failure in a plant protection signal. Interruption/intrusion was defined as everything that interrupted the ongoing task for a while. Figure 1 shows the interruptions encountered by shift supervisors, and reactor and turbine operators in three crews within a period of 40 min from the beginning of the failure to the end of the session. As can be seen, the shift supervisors were interrupted a bit more often than the other operators. For the shift supervisors, there also seems to be somewhat more interruptions in the first part of the scenario than in the latter part.

On the other hand, the interruptions were longer for reactor operators than for the other operators (see Fig. 2). Tasks that were most often interrupted were procedure reading/handling, monitoring screens, and panel operations. It was also found that a response to an interruption was typically immediate – as if the operators thought that the interruptee is obliged to respond immediately to the interrupter so that the latter does not need to wait for a long time.

A preliminary categorization of interruptions and their causes was conducted. In general, external interruptions were caused by alarms, phone calls and verbal expressions of other personnel. The response to an interruption was typically immediate. The shift supervisors interrupted reactor or turbine operators by asking a question or informing them on issues of importance more frequently than the other way around. This finding can be understood in that the shift supervisors are responsible for the main operational decisions, and they also have the main responsibility of co-ordinating the operators' work and communicating with people outside the CR. As said above, at the first phases of the scenario the shift supervisors were frequently interrupted, and they also had problems at times to get their tasks accomplished due to these interruptions.

We also observed the operators' procedure use from the perspective of multitasking. It was found that self-initiated interruptions were a characteristic feature of NPP CR operator multitasking. For example, operators had to frequently move from one user interface to another to seek information or to conduct a particular control action, and sometimes they had to shift their attention from one procedure path to another and execute a number of procedure steps from the latter path before returning back to the first task. It was, however, found that the operators tried to minimize the

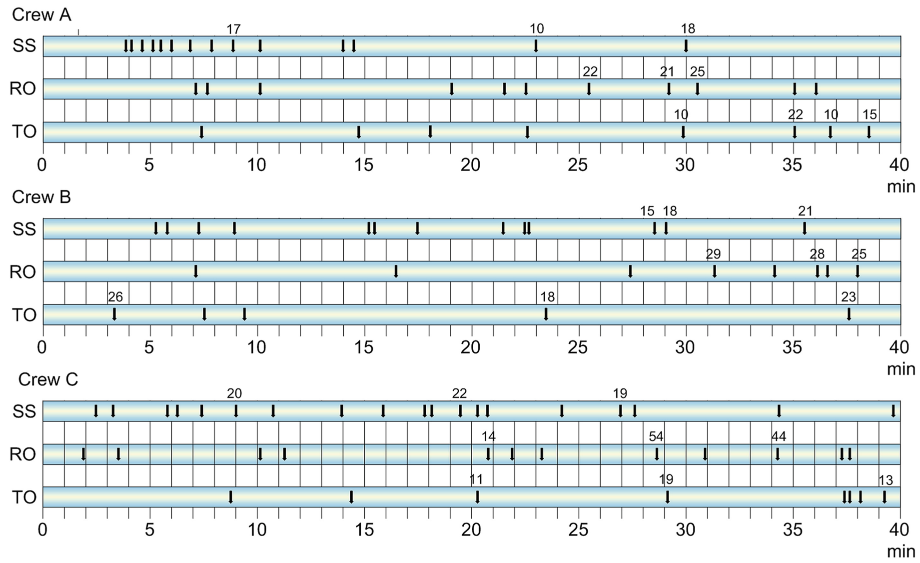

Fig. 1. Interruptions in a simulated accident scenario for three crews and three operator roles (SS = shift supervisor; RO = reactor operator; TO = turbine operator). Each arrow refers to one interruption. The duration of some of the longest interruptions is presented above the arrow (in seconds).

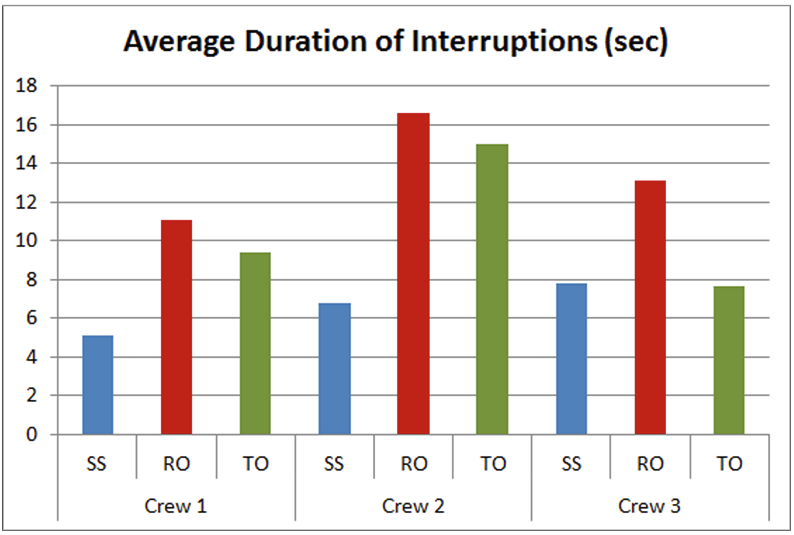

Fig. 2. Average duration of interruptions for three operator crews and for three operator roles

time spent for multitasking, and instead they tried to execute each path from the beginning to the end before they moved to another path. Even though the number of errors caused by task interruptions was apparently small, there was typically a small time delay when operators returned from one task to another.

3.2 Operator Perceptions of Interruptions

Regarding operators' perceptions of interruptions encountered and of frustration caused by these interruptions, it seemed to be that the distracting events that may occur in the CR did not frustrate them very much. The only exception to that were the alarm sounds that disturbed them to some extent. As an answer to the question whether the operator him-/herself interrupted another operator while the colleague was executing some task, the respondents thought that they did it at least a couple of times during the simulation run.

However, according to the survey, the operators still thought that the task at hand was sometimes interrupted due to background conversations, alarm sounds, and phone ring tones. As can be seen in Fig. 3, turbine operators were interrupted more frequently than the other operators by alarm sounds, other operators, and background conversations; shift supervisors were, in turn, more frequently interrupted by phone ring tones. This finding simply reflects the fact that a larger proportion of all phone calls are addressed to the shift supervisors.

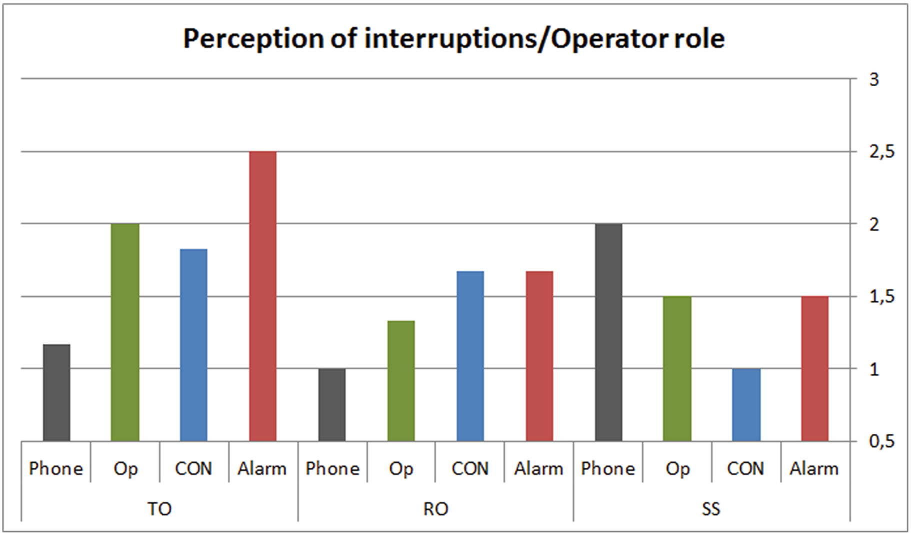

Fig. 3. Perception of some types of interruptions in the three operator positions. It was asked whether task accomplishment was interrupted during the session by the presented factors (Phone = phone ring tone; Op = another operator; CON = background conversation; Alarm = alarm sound) in a rating scale ranging from 1 to 4.

4 Conclusion

Our results have implications for theories of interruption management. According to the findings, existing views present a too simplistic view of the role of interruptions in multitasking, since they do not take into account the effect of task context on the specification of interruptions. For example, in the CR settings, it depends on the task performed whether, for example, an operator's utterance is defined as an interruption or a necessary element in a normal conversation.

We suggest that negative consequences of interruptions can be alleviated, for example, by better procedure and user interface design, alarm management, and team training. As an example of a procedure design issue, we state that strict adherence to procedures may even increase the adverse effect of interruptions: when using the procedure in a more adaptive and resilient way, the operator may better consider the total situation and therefore anticipate the interruptions. A more adaptive way of working requires that the operator is able to hierarchically decompose the main task into separate simple tasks, and he/she relies to a sufficient extent on knowledge in the world to guide him/her from one task to another.

If we look at multitasking and interruption handling especially from the perspective of resilience engineering, many conversational interruptions can support the enactment of resilient strategy and are thus useful (for examples of behaviors supporting resilience, see [36]). However, it is equally true that excessive multitasking and constant interruptions cause vulnerabilities that can result in errors and other problems.

Expert workers' ability to multitask is a resource that will be useful in a state of emergency. On the other hand, in normal work situations, the amount of work should be adjusted to the optimal level so that people have time to think and anticipate. The absolute aim must be that there should be no situations, in which people have no time to think.

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