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Combining control room operator task load analysis and subjective workload assessment

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This study presents and compares results from task load and subjective workload assessment in an offshore petroleum control room and a hydro and wind power control room, combining methods for subjective and analytical estimation of task load. Results from the task load estimates for both control rooms are coherent and indicates that the amount of planned work should not occupy more than a maximum of 75% of the time available on a shift, which is in line with observations from previous studies and literature. Use of the Subjective Workload Assessment Technique (SWAT) measures added additional insight regarding what type of new tasks the control rooms could undertake, depending on the control room staff's composition of competence and experience. The results from the studies were used as a judgment criterion to decide whether it was necessary to reallocate tasks within the control room or adjust the number of control room staff. Findings from the study were compared to recommendations from the literature and insights from the specific method use are discussed.

Keywords: Task load, Workload, Process industry, Task analysis, Function allocation, Analytic workload.

1. Introduction

Extended opportunities for remote-control accelerates centralization of control room tasks. In the later years industrial actors want to utilize the opportunities provided by remote control technology to extend existing control rooms and operation centers to take on a wider portfolio of both well-known and new control tasks. At the same time the transition from fossil to green energy production entails an increasing complexity in the energy system with associated requirements for understanding by operators who must control the production.

This study presents and compares results from task load and subjective workload assessment in an offshore petroleum control room and a hydro and wind power control room, combining methods for subjective and analytical estimation of task load. The petroleum control room had to decide whether the staffing was sufficient to keep control of topside and subsea production units. For the electricity production control room, the situation was similar, but in addition considering extension of their responsibility for control of additional wind farms and production of hydrogen from electricity.

2. Theoretical Background

2.1 Workload definition

Mental workload is a complex multidimensional concept. The theoretical work explaining its underlying mechanisms has been debated for more than four decades, and the work of describing, understanding and defining the concept will probably continue far into the future. Longo et al. (2022) explains the lack of a fully established research framework for workload by pointing on the lack of common agreed definitions and different theoretical assumptions used as basis for definitions and measurement techniques. In a comprehensive analysis of theoretical approaches, measures and definitions, they argue that multiple definitions complement each other and propose a synthesis of 68 definitions:

«Mental workload (MWL) represents the degree of activation of a finite pool of resources, limited in capacity, while cognitively processing a primary task over time, mediated by external stochastic environmental and situational factors, as well as affected by definite internal characteristics of a human operator, for coping with static task demands, by devoted effort and attention."

For use in a critical safety industry control room this definition recognise that the human operator has a number of limitations when it comes to resources, that (s)he is being at the mercy of circumstances in the processes to be monitored and that internal characteristics are important. Being a synthesis of definitions, it is not surprising that the definition is in line with other works referring to workload as the portion of the operator's limited capacity required to perform a particular task. Young et al. (2015) makes an analogy between mental and physical workload. Demands can have multiple facets, such as time pressure and task complexity and there will always be variation in amount of resources and quality of resources available to cope with the situation. Defining workload in terms of this balance between demand and resources (Longo et al., 2022; Young et al., 2015; Wickens and Hollands; 2000) offers a great advantage when it comes to developing practical and less resource-intensive measurement techniques.

2.2 Measurement of workload

Traditional test and evaluation methods range from interviews to measurement of operator performance and workload measurement in full-scope simulator test scenarios.

Depending on the starting point for classification, literature normally describe 3 or 4 different types of mental workload measures. These are self-report or subjective measures, performance measures, psychophysiological and analytic measures. A comprehensible taxonomy of methods is described in Rusnock, Borghetti and McQuaid (2015). They categorize measures across the two dimensions objective–subjective and empirical–analytical. In this taxonomy analytical measures can be divided between subjective analytical methods and objective analytical methods. The subjective analytical methods are typically suitable for early design phases of new products or systems and rely upon subject matter experts making estimates based on early system descriptions. Objective analytical methods can be built from task analysis with input from operation and experience with similar systems or situations.

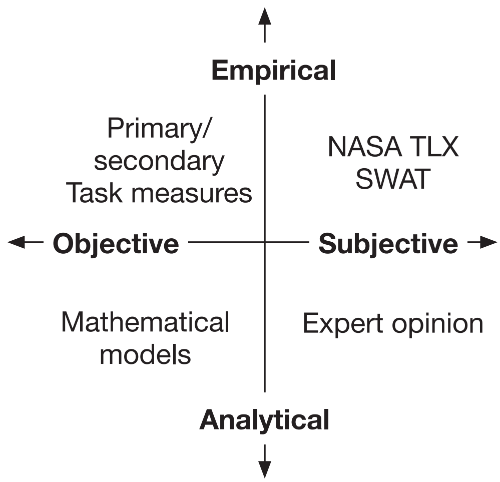

Figure 1. Dimensions of workload as presented in Rushnock, Borghetti and McQuaid (2015)

Workload is defined as a multidimensional concept. Multidimensional ratings assumes that component factors can be evaluated by operators more reliably than a holistic assessment. These measures provide information about the specific sources, as well as providing a summary. Two popular multidimensional ratings are the NASA Task Load Index (NASA-TLX, Hart and Staveland, 1988), and the Subjective Workload Assessment Technique (SWAT, Reid and Nygren, 1988) developed by the US Air Force Armstrong Aerospace Medical Research Laboratory. The SWAT measure uses three levels (low, medium, and high) for each of the three dimensions of time load, mental effort load, and psychological stress load to assess workload.

One important implication from the demand resource limitations ratio is that task load is a central component and indicator of mental workload and that measures of task load have been found to predict workload quite well (Ghalenoei et al., 2022). Lysaght et al. (1989, 56) refers to stress as the ratio of the sum of the average task execution times to the total time available.

2.3 Industry Guidance on workload

Typical objectives of task and function allocation for control room operation are to modify the responsibilities of the team members to reduce the workload, increase productivity and adjust staffing according to needs. Human factors project guidance and standards describe the work with function and task analysis (ISO-11064, IEC 60964, IEC 61839, NUREG 0711, EPRI 1008122). Definitions of a task vary somewhat between the guidance documents and e.g. EPRI uses the term «functions» in a less restrictive sense than in the NUREG 0711 document. This paper defines a task as actions performed by the operator for the accomplishment of a functional goal. The subjective and task analysis based measure used, is based on the assumption that task load is an indicator of workload and that it is proportional to the ratio of the time occupied performing tasks to total time available. (Drøivoldsmo, Nystad and Lunde-Hanssen, 2022, Longo et al., 2022; Kirwan and Ainsworth, 1992; Gawron, 2008). This implies that if a task is judged as being busy with a measurable task in a time interval, task load is 100% during that interval.

2.4 Staffing

Control room staffing levels has traditionally been estimated based on studies of critical scenarios, ensuring that the crew has time to take necessary preventive actions to keep control of the process. Human factors standards and guidance for staffing put forward a set of competence requirements and a general statement about a sufficient number of skilled professional staff to handle normal and emergency operations. The recommendation for early project staffing analysis is to use the results from function and task analysis to identify basis for judgement of whether the number of functional goals and the workload rate required of the control room staff will exceed their capability.

2.5 Task load and performance

A central question for workload is when the task demand exceeds the limit for acceptable performance. Young et al. (2015) interprets task demand as associated with mental workload and performance (figure 2) indicating both an underload and overload redline.

There is an absolute limit of task performance when 100% of the operator time is occupied performing tasks. Recommendations are that planned task load should never exceed approximately 75% of the time available. This recommendation is in line with Kirwan and Ainsworth (1992, 143 and 293) where they consider satisfactory task load in the interval between 50% and 75% of the available time to carry out the tasks. Insights from timeline analysis indicates a limit of about 75-80% (Beevis, 1992: Parks and Boucek, 1989; Young et al., 2015). In Drøivoldsmo, Nystad and Lunde-Hanssen (2022) we argue that this limit will be relevant for the situation of subject overall workload.

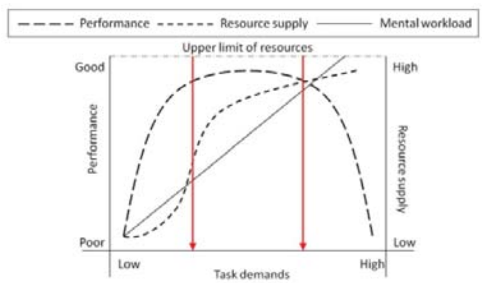

Figure 2. Supply–demand relationship associated with mental workload and performance as described by Young et al. 2015. The origin of the figure is from de Ward (1996).

The space between right red line and 100% percent of task demand in figure 2 can be seen as the reserve capacity region for the operator task load and the red line is then the limit for when errors in performance begin to occur (Parks and Boucek, 1989). The area to the left of the left-most red line in figure 2, representing low workload, is more problematic. *"While defining thresholds for overload might be difficult, doing the same for underload is approaching the impossible for the time being. The theoretical underload redline does exist and is illustrated on Figure 2, but identifying or quantifying it remains elusive."* (Young et al. 2015).

3. Objective and research questions

The purpose of this study has been to establish more knowledge about analysis of task load as an indicator of workload, the feasibility of time estimates as data input, and the value from combining these data with subjective measures of workload to optimise control room staffing.

What can results from analytical task load studies tell us about the overall control room workload and how can combination of measures contribute to improve the quality of measurement?

4. Method

Using the Integrated Operations Man Technology Organisation (IO MTO) mapping technique (Nystad and Drøivoldsmo, 2012; Drøivoldsmo et al., 2022) all work tasks that are performed during a "normal" working day were described for both the petroleum and the electricity production control room, and for all operator positions and shifts. The underlying idea of workload assessment using the IO MTO mapping technique is that it allows for computing the time required to perform the different tasks carried out by control room operators will allow to determine their remaining time to make an update of their own situation understanding and keep control of the process.

In the period August to November 2022 a total of approximately 500 work tasks was mapped and described by up to 25 different parameters with time estimates and type of task as the most central parameters. Both control rooms under study had been in operation for more than 10 years and had staff with extensive experience in controlling petroleum production and hydro power respectively. For subjective workload assessment, the dimensions of the Subjective Workload Assessment Technique (SWAT) were translated into Norwegian and used together with scenario descriptions. Further, the time load dimension of SWAT was used to establish a time load baseline throughout the day.

4.1. *Mapping of work tasks*

3-4 representatives from the relevant control room positions participated in workshops over 2 days. In addition, operational managers or project managers with technical competence participated in the workshops. All tasks performed by each position was described in detail by core parameters including time of day, task duration, frequency of task (day, week, month, year), responsible role, other roles involved, type of collaboration, information need and need for equipment/systems. Other parameters were included depending on the need in each study, e.g. HSE aspects and task criticality. The tasks were categorised according to requirements for urgency and attention: P = Tasks that can be performed in parallel with other tasks; M = Main task, these require full attention and cannot be performed in parallel with other tasks; O = "On demand", are performed on request or when required, while other tasks must wait; and F = Free tasks, not time-critical and can be performed when the operator has time.

Tasks occurring regularly as well as more sporadic and irregular tasks were mapped. For all task durations an average duration estimate per shift was calculated. To account for over- or underestimation of task durations by the informants, the method applied a procedure for normalization of task durations for the tasks that were performed in parallel with other tasks (P tasks). The rationale was that it is typically these parallel tasks that are difficult to estimate correctly. The normalization ensured that the sum of estimated task durations equalled the time available on the shift. A normalization factor X was calculated as the sum of the duration of non-parallel tasks (M, O and F tasks) subtracted from the total time available on the shift (A) and divided by the sum of the duration of the parallel tasks P, as shown in formula 1 below. Each P-task was then multiplied with the normalization factor X to arrive at the normalized parallel task durations, P_N.

$$X = (\Sigma\ (F+O+M)) / P \qquad (1)$$

4.2. *Workload estimation (SWAT)*

Subjective workload was estimated by control room operators using the Subjective Workload Assessment Technique (SWAT) developed by Reid and Nygren (1988). SWAT is a subjective rating technique where workload is scored on three dimensions: time load, mental effort load and psychological stress load. All three dimensions were used to assess workload for selected scenarios, while only the time load dimension was used to provide a measure of workload across the whole shift. To increase the variation of the estimates, the original scale from 1 to 3 was changed to a seven-point scale.

5. Results and discussion

Estimates for operator time available to maintain overview and control of the process were used as a dependent measure in both cases presented below.

5.1. Case A: Petroleum

For the petroleum control room, task load estimates were made for two operators (O1 and O2) as well as two different situations, normal task load situation and a high task load situation with higher activity in the production plant and more responsibility on one of the operators. As shown in Figure 3, the available time for maintaining overview of the process in the normal load situation ranges from 34% to 43% among different operators and shifts.

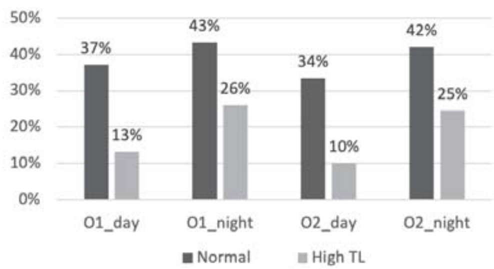

Figure 3. Available time to maintain overview of the process shown in percentage of total task time.

In the high task load situation, one of the day shift operators has as little as 10% time available for this core task. Given the anticipated accuracy and experience with use of the method (Drøivoldsmo et al. 2022) this indicates a need for measures like increased staffing or reallocation of tasks.

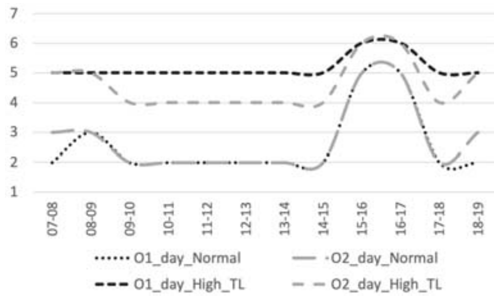

Figure 4. Rated time load across the shift for day shift operators.

The time load dimension from a 1 to 7 scale based on SWAT descriptions (Figure 4) indicates that the time interval from 15 to 17 is the interval where the operators have the highest perceived task load. The night shift was also rated but showed minimal variation from a low level.

Task criticality was scored based on the combined rating of consequences of human error and degree of human involvement in a single task. This score was used to control for coinciding occurrence of high task load and a high proportion of critical tasks. The analyses showed that the proportion of critical tasks in the period in question with a high task load was large. This was also confirmed by the operators who described the situation as they had insufficient time in this period to carry out all tasks.

5.2. Case B: Electricity production

Task load estimates were made for two different scenarios: one scenario with a current task load situation and a second scenario with the control room taking responsibility for additional production facilities (Figure 5). For daytime and afternoon shifts, the time available for updating the situation understanding and control of the process was below the recommended limit in both scenarios and requires measures.

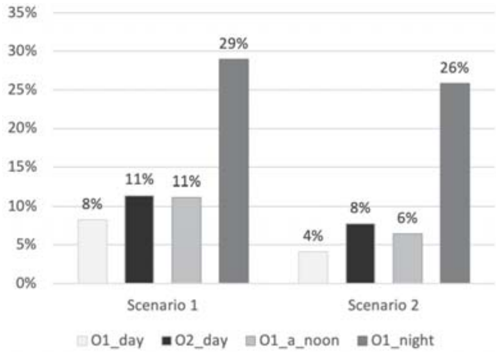

Figure 5. Calculated task load for two daytime-, afternoon- and nigh shift operators. Scenario 1 describes task load in the current situation. In scenario 2, additional control tasks have been added.

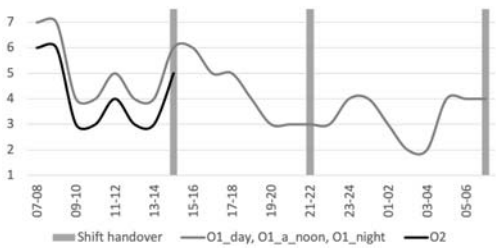

Figure 6. Rated time load for day, afternoon and night shift operators.

An assessment was made of the extent to which new tasks, introduced in scenario B, can be managed outside of busy times of the day (figure 6). The conclusion was that most new tasks could occur at any time during a shift. In this case the average duration of new tasks that always can be managed outside of busy periods was only approx. 20% of estimated time use for new tasks.

As a test of the full SWAT scale (time load, mental effort, and stress load), a number of normal and worst-case situations were defined and scored by the operators. The scores from this exercise proved to be a valuable contribution to the challenges of taking new tasks into the control room. The scores for psychological stress helped to identify challenges resulting from great responsibility and the need for maintenance and training on tasks that are rarely carried out by the operators.

Use of the SWAT measure

The authors are aware that the practical application of the SWAT time load scale as an post hoc analysis is not in line with the intended use of SWAT. The intended use of this measure is to apply the measure shortly after or during (in a short break) a time-limited real-world or simulator scenario. However, with a good match to the process domain, the SWAT scale is described, tested, and well reputable, and there were no better alternatives available. Since the scoring did not take place immediately after a situation, the operators could spend time discussing and agreeing upon time load estimates. More time for assessment and fine-tuning opened the possibility of increasing grades on the scale from 3 to 7 steps without this being perceived as demanding during the data collection. The same procedure and scales for measurement of time load were used in both case A and case B. In case A an attempt was made to use the full SWAT scale directly on some of the task descriptions. This procedure failed, and for case B it was decided to describe normal and worst-case scenarios for applying this measure.

Limits for task load

Results from the task load estimates for both control rooms are coherent and indicate that the amount of planned work should not occupy more than a maximum of 75% of the time available on a shift, which is in line with observations from previous studies and literature (Beevis, 1992: Kirwan and Ainsworth, 1992; Parks and Boucek, 1989; Young et al., 2015).

Mapping work tasks with time estimates does not seem to work as well for "underload" as for high workload. This study has not produced numerical material for this issue, but use of the task mapping method normalization procedure (Drøivoldsmo et al., 2022) over time, gives a strong suspicion that control rooms with a small task load tend to overestimate and overreport the time spent on the individual task. The practical implication of this reporting problem is that the current normalisation of task time cannot be used for "underload" estimates.

Task load measurement

Most activities performed in a control room are by their nature such that they involve several types of work tasks. This means that a global measure of workload in most cases will fail to identify the contribution of each sub-task or component. Using task mapping and analysis of task load as a global indicator will not constitute a detailed estimation of operator workload. Nor does it intend to identify variations and the individual sub-task's contribution to workload. Using time estimates for task load, the purpose of this measure is to identify staffing requirements and ensure job design to avoid situations where operators have reduced opportunity to identify risks. The ratings from the SWAT time load dimension made an important contribution to deciding the frequently asked question of whether the control room can take on more work tasks. Although the total task load for a control room is rated as high, this load is not necessarily equally distributed over the day or the same for weekends and weekdays. Use of the modified SWAT measurement added additional insight regarding what type of new tasks the control rooms could undertake, depending on the control room staff's composition of competence and experience and at what times of the day it was possible to take in more tasks. The combination of task load and SWAT time load allowed for a more detailed identification of load peaks for certain time intervals. In intervals where the load is calculated as close to, or greater than, 80%, operators should not have more work tasks with a high degree of criticality allocated.

The results from the studies were used as a judgment criterion to decide whether it was necessary to increase the control room staff. The combination of measures across the empirical - analytical dimension (Figure 1) showed to be effective for extending task load as an indicator of operator workload and was useful for making decisions about measures for optimizing workload in the control rooms under study. There are currently, to the authors knowledge, not developed any dedicated standards or regulations requirements for measurement of control total workload pertaining to the transition of single- to multiunit control. Nor for situations where the operators must handle several safety critical process domains in parallel from the same control desk. For this purpose, the results from this study could be useful input for future work with development of analytical workload measures, standards and guidelines.

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