Neerincx, M.A., Veltman, J.A., Grootjen, M. & Veenendaal, J. van (2003). A model for cognitive task load prediction: Validation and application. *Proceedings of the 15th Triennial Congress of the the International Ergonomics Association*. Seoul, Korea: IEA2003.

A MODEL FOR COGNITIVE TASK LOAD PREDICTION: VALIDATION AND APPLICATION

Mark A. Neerincx, TNO Human Factors, The Netherlands, neerincx@tm.tno.nl
J.A. (Hans) Veltman, TNO Human Factors, The Netherlands, veltman@tm.tno.nl
Marc Grootjen, Royal Netherlands Navy, The Netherlands, marc@grootjen.nl
Johan van Veenendaal, Royal Netherlands Navy, The Netherlands

This paper summarizes a Cognitive Task Load (CTL) model, which describes the effects of (envisioned) task allocations and support functions on operator performance and mental effort. The CTL-model distinguishes three load factors: the classical measure percentage time occupied, the number of task-set switches and the level of information processing. Recently, the model has been used to guide several system development processes. We present a validation study and an example application for the analysis of envisioned task distributions and support functions on a ship. This CTL-analysis provided requirements for dynamic task allocation and a first design of support functions that extend human capacities for the three factors of the CTL model.

COGNITIVE LOAD THEORY

Cognitive Task Load

Due to the application of information technology and concentration of work in a central control room, fewer personnel will be involved in the supervision of complex technical systems. For standard situations the personnel may have the required work organization, capacities, skills and tools to perform their tasks effectively and efficiently. However, these resources may deficit for managing non-standard, high-demanding situations. In order to automate systems adequately, we need models and methods to predict the effects of specific task settings and computer support functions on operator task performance. We developed a Cognitive Task Load (CTL) model and method for analyzing (envisioned) task load distributions among control room crew (Neerincx, 2003, to appear). The CTL-model distinguishes three load factors that affect operator performance and mental effort: the percentage time occupied, the number of task-set switches and the level of information processing.

The *percentage time occupied* has been regularly used to assess workload in practice for time-line assessments. Such assessments are often based on the notion that people should not be occupied more than 70 to 80 percent of the total time available. The CTL-model distinguishes *task-set switching* as an additional load factor in the performance of process control tasks. Complex task situations consist of several tasks, with different goals. These tasks appeal to different sources of human knowledge and capacities and refer to different objects in the environment. We use the term task set to denote the human resources *and* environmental objects with the momentary states, which are involved in the task performance. Switching entails a change of applicable task knowledge on the operating and environment level. A third load factor, the *level of information processing,* addresses the effects of task complexity based on the Skill-Rule-Knowledge framework of Rasmussen (1986). At the skill-based level, information is processed automatically resulting into actions that are hardly cognitively demanding. At the rule-based level, input information triggers routine solutions (i.e. procedures with rules of the type ‘if <event/state> then <actions>’) resulting into efficient problem solving in terms of required cognitive capacities. At the knowledge-based level, based on input information the problem is analyzed and solutions are planned, in particular to deal with new situations. This type of information processing can involve a heavy load on the limited capacity of working memory.

Three Dimensional “Load Space”

The combination of the three load factors determines the cognitive task load: the load is high when the percentage time occupied, the level of information processing (i.e. the percentage knowledge-based actions) and the number of task-set switches are high. Figure 1 presents a 3-dimensional "load" space in which human activities can be projected with regions indicating the cognitive demands that the activity imposes on the operator. It should be noted that these factors represent task demands that affect human operator performance and effort (i.e. it is *not* a definition of the operator cognitive state). In practice, operator activities will not cover all possible regions in the cube of figure 1. A higher level of information processing may cause the time occupied to increase. Also a larger amount of task-set switches may cause the time occupied to increase because the costs of these switches are so severe that the operator needs more time to execute the task. The cognitive task load analysis of this chapter aims at a cube that is "empty" for the critical regions such as distinguished below, by designing adequate task allocations and support functions.

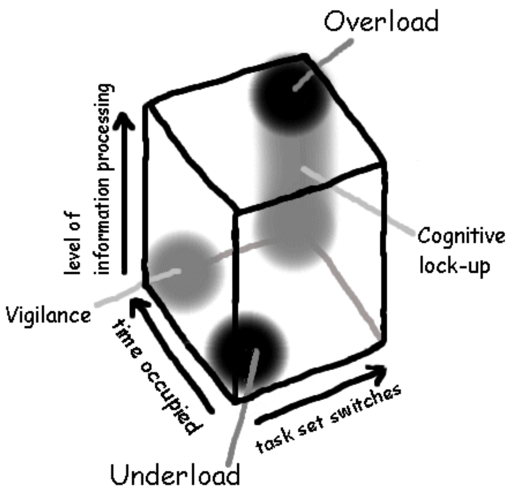

Figure 1: The three dimensional model of cognitive task load with four general problem regions.

It should be noted that the effects of cognitive task load depend on the concerning task duration (see table 1). In general, the negative effects of under- and overload increase over time. *Under-load* will only appear after a certain work period, whereas (momentary) *overload* can appear at every moment. When task load remains high for a longer period, carry-over effects can appear reducing the available resources or capacities for the required human information processing. *Vigilance* is a well-known problematic task for operators in which the problems increase in time (Parasuraman, 1986). Performance decrease can already occur after 10 minutes when an operator has to monitor a process continuously but does not have to act. Vigilance can result in stress due to the specific task demands (i.e. the requirement to continuously pay attention on the task) *and* boredom that appears with highly repetitive, homogeneous stimuli. Recent research on *cognitive lock-up* shows that operators have fundamental problems to manage their own tasks adequately. Humans are inclined to focus on one task and are reluctant to switch to another task, even if the second task has a higher priority. They are stuck to their choice to perform a specific task and have the tendency to execute tasks sequentially (Kerstholt & Passenier, 2000). In general, empirical research should provide the data to establish the exact boundaries of the critical regions for a specific task domain (e.g. by expert assessments and/or operator performance evaluations).

Cognitive Support

The CTL-theory distinguishes four "generic" support functions that affect cognitive load and human performance. The **Information Handler** filters and integrates information to improve situation awareness, i.e. knowledge of the state of the system and its environment, and reduces the *time occupied*. Due to the increasing availability of information, situation awareness can deteriorate without support. Correct information should be presented at the right time, at the right abstraction level, and compatible with the human cognitive processing capacity. The **Rule Provider** provides normative procedures for solving (a part of) the current problem and affects the *level of information processing*. Due to training and experience, people develop and retain procedures for efficient task performance. Performance deficiencies may arise when the task is performed rarely so that procedures will not be learned or will be forgotten, or when the information does not trigger the corresponding procedure in human memory. For these situations, rule provision aims at supplementing human procedural knowledge. The **Diagnosis Guide** affects the *level of information processing*. This support function guides the operator during the diagnosis resulting in an adequate problem-solving strategy for a specific task. The **Scheduler** affects the number of *task-set switches* by providing an overall work plan for emergency handling. Task priorities are dynamically set and shown in a task-overview to the operator resulting in effective and efficient switches.

VALIDATION

Cognitive Task Load

Recent laboratory experiments provided empirical support for the model, showing effects of each load factor on performance measures and mental effort. We conducted experiments in controlled laboratory settings and in more complex, realistic settings to systematically test the theory and investigate its application in the "real world". In this research approach, the test environment subsequently increases in complexity and decreases, therefore, in controllability, so that we can test and refine the theory, *and* achieve a good understanding of its applicability in practice. Two laboratory experiments showed that "level of information processing" and "task-set switching" can affect operator performance and mental effort substantially, in addition to the classical load measure "time-occupied". Furthermore, the negative effects of the load factors proved to reinforce each other in the lab experiments. Subsequently, we conducted an experiment in a realistic ("high-fidelity") Ship Control Center simulator of the Multi-purpose frigate of the Royal Netherlands Navy as a further validation study. Application of the CTL-*method* resulted in the specification of 8 scenarios and crew action sequences from which the three (estimated) load factor values could be derived per operator. Subsequently, 13 crews had to perform these 8 scenarios. The estimated load values proved to correspond well with the actual levels during task performance. In correspondence with the CTL-*model*, the three load factors proved to have a substantial effect on operator performance and effort, showing under- and overload situations.

Cognitive Support

We applied the four support concepts in the design of user interfaces for several systems. For example, Grootjen et al. (2002) designed such a user interface for a ship's bridge. Subsequently, they conducted an experiment to test the effects of the support functions, under high and low task load, on task performance, mental effort and possible side effects (such as operator's loss of situation awareness). In this experiment, 50 students of the Royal Netherlands Navy had to solve damage control problems with the prototype interface. The support proved to result in substantial effectiveness and efficiency profits, i.e. the use of support functions leaded to a substantial improvement of task performance, especially at high task load. Possible costs of being "out of the loop", like inadequately reacting on an implemented wrong advice or a decrease in understanding of performed actions, could not be found.

APPLICATION

Neerincx (2003, to appear) provides a method and description format to systematically create and assess normal *and* critical situations with their corresponding action sequences. Such an action sequence displays actions of different actors on a time-line, including the interaction with support systems. The actions can be triggered by events, and are grouped according to their higher-level task (goal).

Van Veenendaal (2002) assessed the action sequences for alternative designs of the naval ship's bridge, comprising different task allocations and support functions for navigation and platform supervision. Normal and critical *scenarios* were specified with domain experts. Furthermore, for every scenario, support functions were specified and included in the action sequence specifications (i.e. information handler, rule provider, diagnosis guide and task scheduler). The action sequences were validated with domain experts. The *cognitive load* model was used to assess these action sequences, each sequence with and without the four support functions. First, the three load factors were calculated per 6 minutes task performance, showing the dynamic load fluctuations in the 3-dimensional load cube of figure 1. Subsequently, via questionnaires experts assessed the action sequences to acquire subjective load measures and estimations of the support effects. The analysis showed that the task of the Officer of the Watch could be extended with platform control tasks under normal conditions. The support functions will complement the knowledge and experience of the bridge crew to realize an adequate performance level. In critical situations however, extra, technical personnel has to be called up. This CTL-analysis provided the first conditions for which the platform supervision have to be (temporarily) assigned to a separate 'ship control crew' (e.g. by calling up maintenance engineers). Furthermore, the CTL-analysis provided a first design of support functions that extend human capacities for the three factors of the CTL model, enabling and enhancing the proposed dynamic task allocation.

DISCUSSION

The human role in complex task environments will be more and more focused on handling non-routine situations supported by information technology. Human task complexity increases as well as the information velocity and ubiquity. Cognitive task analyses are needed to realize an adequate human resource deployment by training, selection, task allocation and cognitive support system. Current task analysis approaches are however diverse and differ on a number of dimensions such as scope, theoretical and empirical foundation, and utility. There is a tension between basic and applied research and insufficient correspondence between individual and team-oriented perspectives. Methods based on cognitive theory, models and architectures made progress, but are still in research state or prove to be hard to apply for real-world, complex tasks. To enable well-founded analyses in such task environments, we have been developing a CTL model and method in an iterative process. Although, there is already sufficient empirical foundation for applying the current version of the model and method, further refinement and validation is required to derive absolute measures for the critical load regions.

Recently, we developed a first prototype tool for the proposed, systematic exploration of the "design space" by assessing the operator load for different task allocations and support functions. For envisioned scenarios, the analyst specifies several levels of crew experience, task allocations and support functions, and the simulator subsequently calculates the corresponding load distributions among the crew (including possible occurrences of momentary peak values) and the overall task execution time of the crew. The CTL-simulator tool allows a systematic, qualitative comparison of design proposals for different task contexts, showing the relative consequences of design choices. The current version of the tool, however, needs further improvement with respect to its usability and empirical foundation.

ACKNOWLEDGEMENTS

This research requires extensive domain knowledge and Human Factors expertise and is based on a continuing co-operation between TNO Human Factors and the Royal Netherlands Navy with contributions of a lot of people. Thanks are due to all of them, in particular Eddie Flohr and Sasja van Besouw.

REFERENCES

Grootjen, M., Neerincx, M.A., Passenier, P.O. (2002). Cognitive task load and support on a ship's bridge: Design and evaluation of a prototype user interface, *INEC 2002 Conf. Procs,* pp. 198-207. London, England: IMarEST.

Kerstholt, J.H., & Passenier, P.O. (2000). Fault management in supervisory control: the effect of false alarms and support. *Ergonomics, 43*(9), 1371-1389.

Neerincx, M.A. (2003). Cognitive task load design: model, methods and examples. In: E. Hollnagel (ed.), *Handbook of Cognitive Task Design*. Chapter 13. Mahwah, NJ: Lawrence Erlbaum Associates.

Neerincx, M.A. (to appear). Designing task allocations and cognitive support. *IEA XVth Congress*, August 24-29, 2003, Seoul, Korea.

Rasmussen, J. (1986). *Information processing and human-machine interaction: An approach to cognitive engineering*. Amsterdam, Netherlands: Elsevier.

Parasuraman, R. (1986). Vigilance, monitoring, and search. In Boff, K.R., Kaufman, L. & Thomas, J.P. (eds.), *Handbook of perception and human performance*, volume 2: cognitive processes and performance, chapter 43. New York: Wiley.

Veenendaal, J. van (2002). Mental load Officer of the Watch: An explorative study on the possibilities to add tasks and computer support on the bridge [in Dutch]. Master's thesis. Royal Institute for the Navy, Den Helder, The Netherlands.