The CLAM Handbook

Cognitive Load Assessment for Manufacturing (CLAM) Handbook

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INTRODUCTION TO THE HANDBOOK

The overall purpose of the ***Cognitive Load Assessment for Manufacturing method*** (hereafter denoted the CLAM method) is to help identifying and assessing the occurrence of cognitive load in manufacturing personnel, as well as educating and assisting manufacturing companies to reduce cognitive load in the personnel at the shop floor early on. The CLAM method is an *inspection method* and has primarily been developed as a proactive approach for workstation design and evaluation. It is designed for quick assessment of cognitive load connected to tasks and workstation design. The motivation for this approach, focusing on identification of relevant issues pro-actively, may lead to effective and efficiently changes in the existing manufacturing environment. The overall goal with the CLAM method has been to make it cost efficient, taking a holistic perspective (both work task and workstation as a whole), saving time and resources in assessing assembly workers' cognitive load in manufacturing.

The CLAM method considers both assembly tasks and workstation layout/design for the assessment. By addressing and identifying cognitive load problems proactively, and designing the workstation and the assembly task properly, one avoids high cognitive load in the personnel. High cognitive load during pro-longed longer time-frames, may lead to inefficient work procedures, bad performance, high error rates, low acceptance as well as ergonomic and mental health symptoms in the personnel.

The developed CLAM method and its assessment tool are designed to be used by non-experts, i.e. it will not require a researcher or anyone with any major knowledge of human cognition, cognitive psychology or human factors. This handbook is intended to make the method usable by different user roles, most usually engineers, production leaders, technicians, and assembly workers.

The CLAM handbook consists of four parts:

- It contains a **background part,** where underlying relevant theories of the human cognitive systems (strengths and limitations) and especially cognitive load are briefly presented. It is also emphasized why it is important to consider these issues within manufacturing.

- It consists of an **instruction part** of how to use the CLAM assessment tool, either individually or pluralistically. It briefly introduces the 11 factors as well as the overall procedure of how to assess the factors. This part also contains the necessary material in order to apply the CLAM assessment tool by providing instructions for how to use it.

- It provides a **description part** that presents in more details how the 11 different factors could be observed and the procedure regarding how to assess them in manufacturing as well as what kinds of cognitive load they could result in. This part provides guidance to the evaluator(s) how to

interpret and understand a particular factor and offers suggestions on why a particular score should be assessed at a certain level of cognitive load.

- It finally provides a **result and recommendation part** that concerns how to interpret and use the obtained overall result of the CLAM assessment tool, which is a calculated result of the 11 factors. It also provides some recommendations that can contribute to reducing high cognitive load (when identified) in order to minimize identified problems of high cognitive load, and thereby improving manufacturing.

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BACKGROUND: THE HUMAN COGNITIVE SYSTEM AND COGNITIVE LOAD

Technology either empowers or frustrates us, but the people designing the technology have the responsibility, and one should credit or blame the designer of the technology and not technology itself. Following the line of arguments put forward by Norman in 1996, our goal is to develop a human-centred view of the technologies of cognition. It is not an anti-technological approach, it is pro human. Taken together, technology should be considered as a resource in the creation of a better working environment, it should complement human abilities, aid those activities for which we are poorly suited cognitively, and enhance and help develop those cognitive skills for which we are ideally suited.

Characteristics of human cognition and cognitive load

Cognition has traditionally been described as mental activities that take place inside the human brain. More recent views emphasize the importance of the environment as well as the body of the cognizer as well as the interaction between these factors and the brain. Cognitive abilities enable the human being to experience the world and act in it. Perception, decision-making, problem solving, memory processes etcetera are all cognitive activities that human beings are engaged in every day. They are also cognitive activities that are depending on the cooperation of the body (e.g. the musculoskeletal system and peripheral nervous system) and sensory inputs from the environment as well as the workings of the brain.

Human cognition is comprehensive, but there are limitations. When exposed to stimuli the cognitive system experiences what is commonly referred to as ***cognitive load***. Briefly stated, cognitive load refers to the mental load that performing a specific task imposes on the human's cognitive system. Perception, decision-making, problem solving, attention, memory processes et cetera are examples of cognitive activities that enable the human being to experience and act in the world. These cognitive processes are constantly processing information indicating that human beings always experience some level of cognitive load. The level of cognitive load is constantly fluctuating as a response to the stimuli that the situation, the task, and demands are imposing on the human. This is naturally individually and depending on the individual´s experience and previous knowledge. While some situations make it possible for the individual to perceive and interpret the stimuli and the pattern of information and without an apparent effort generate an appropriate response, some other situations demand conscious awareness and reflection. This implies that some cognitive processes of an individual are more demanding than others.

Different modes of cognition

There are many modes of cognition, in which different kinds of thinking occur. Norman (1996), for example, describes two different types of cognition that are particularly relevant for the CLAM method. He denotes them as *experiential* and *reflective* cognition. Roughly speaking, experiential cognition is characterized by an automatic nature and the reactions to the situations appear to flow naturally. This is likely to be due to experience and perhaps years of training are required in order to

achieve this. Norman (1996, pp. 23) explain this with the words: *"Experiential thought is reactive, automatic thought, driven by the patterns of information arriving at our senses, but dependent upon a large reservoir of experience"*.

The reflective mode, on the other hand, is about concepts, planning and reconsideration. Reflective cognition does often require external support (computational tools, writing, instructions et cetera) and also the support of other people. Norman (1996, pp. 25) expresses: *"Reflective though requires the ability to store temporary results, to make inferences from stored knowledge, and to follow chains of reasoning backward and forward, sometimes backtracking when a promising line of thought proves to be unfruitful. This process takes time"*.

Similarly, Kahneman (2011) differentiates between the automatic operations of *System 1* (which he generally refers to as 'fast thinking', which is similar to experiential cognition) and the controlled operations of *System 2* (which he generally refers to as 'slow thinking', which is similar to reflective cognition). The process of demanding and effortful cognitive work is related to system 2 in which the demands of memory, attention and other aspects of performing non-automatic cognitive tasks actually put some constraints on the cognitive processes, resulting in a slower thinking process because of the limited available cognitive capacity, resulting in increased cognitive load. Broadly stated, Kahneman (2011, p. 20-21) describes the two systems as follows:

- *"System 1* operates automatically and quickly, with little or no effort and no sense of voluntary control.
- *System 2* allocates attention to the effortful cognitive activities that demand it, including complex computations. The operations of System 2 are often associated with the subjective experience of agency, choice and concentration".

Kahneman (2011) points out that some of our cognitive activities become fast and automatic because of prolonged practice, although they from the very beginning needed conscious attention, e.g., reading skills which normally runs on our automatic pilot in the skilled reader. The limited human capacity for *attention* is the central pinnacle for cognitive load, and when acting beyond that limit, failure appears. The division of labour between the two systems is very efficient, it minimises effort and optimises performance, in most of the time. However, System 1 has some biases, and sometimes provides the wrong reaction and it cannot be turned off. This becomes obvious when there is a conflict between the two systems. One major task of System 2 is to overrule or provide a reflective and conscious "second opinion" of the automatic reactions of System 1. This is for instance common when perceiving so called optical illusions, like the Müller-Lyer illusion (see figure 1).
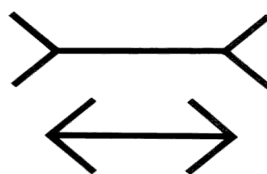

Figure 1. The The Müller-Lyer illusion

Although consciously knowing via System 2 that the two horizontal lines have the same length, the automatically reaction when visually perceiving the two lines via System 1, offers another answer that is hard to deny, namely that the lines seem to be of different length. The reason is that System 1 operates automatically and cannot be switched off by choice, and biases cannot be avoided since System 2 has not received any hint that there might be an error. A promising way to overcome this bias is learning to recognise particular situations in which mistakes are likely to appear. Continuously questioning our thought processes via System 2 is not a viable approach, however, since it is impractical, too slow and has a limited capacity (Kahneman, 2011).

Summing up, the both modes of cognition; (1) *System 1/Experiential cognition* and (2) *System 2/Reflective cognition* are needed and neither is superior to the other, but they differ in requirements and function, as described earlier. It should be pointed out that they are essential for human cognition, although each mode requires different kinds of technical support to function properly. Figure 2 below display the two modes of cognition in the so called "cognitive iceberg" model and visualises that *Experiential cognition/ System 1* are the mode that is less demanding, and has the largest capacity, while the *Reflective mode/ System 2* requires a higher degree of awareness, has a limited capacity, and is the mode we usually assume is the place in which "thinking" actually occurs.

System 2/Reflective cognition – discrete, conscious level with limited capacity for effortful cognitiveactivities.

System 1/Experiential cognition – works in parallel, unconscious, good at pattern recognition, and with a high capacity.
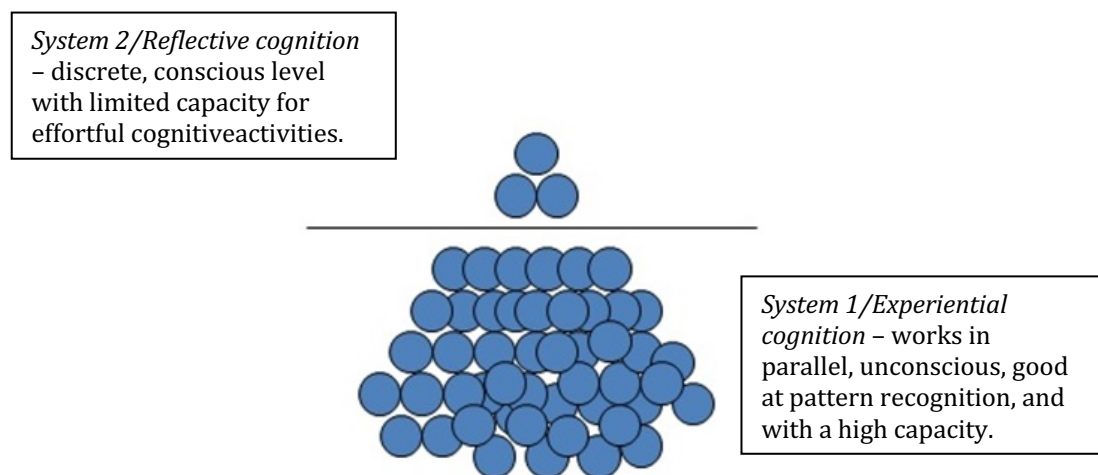
Figure 2. The cognitive iceberg model, depicting the two different types of cognition – System 1/Experiential and System 2/Reflective cognition.

However, these two modes of cognition do not cover the whole cognitive spectrum, but it makes it possible to highlight and compare certain characteristics of human cognition. In everyday life, we use a mix of these modes simultaneously, and the challenge when designing technology is to avoid forcing the use of technology towards one extreme or the other. That is, there is a need to have a proper balance between reflection and experiencing, so the human cognizer is not forced to use her/his limited conscious capacity to interpret the task as such, instead the human cognizer should use the cognitive capacity to solve the problem at hand or make appropriate decisions.

Human beings always experience some level of cognitive load, however this level can change depending on the situation, the tasks and their demands on the individual. For example: an assembly worker performing a manual assembly task is constantly exposed to situations with varying demands. Important aspects to consider concerning the level of cognitive load that the industrial worker can be experiencing is amount of information, time pressure, interruptions, rapid decisions, high variant flora of components and physical layout of workstations. These factors create a cognitive load primarily in combination with each other, where time pressure is assumed to be the triggering factor. Arguably, problems within most of the above factors can be handled with relative ease as long as there is no time pressure. Dealing with poor information design is for instance not a huge problem unless the information has to be dealt with swiftly, as is the case in most industry applications.

It has been recognized in the industry that often the assemblers are provided with too much information rather than the appropriate information, causing information overload for the assembler (Thorvald, 2011). Information overload is a term related to cognitive load. In a manual assembly environment, the problem with information overload is usually due to a combination of high demands on work rate and accuracy respectively, especially in the automotive industry. When the assembler is faced with too much information, the information overload turns into a stressful situation, which causes high cognitive load. Information overload is exemplified in figure 3, where the information on the plastic boards instructs the assembly personnel of what component variant to select and assemble.

Figure 3. An example of too much information in one small area.

Both too high cognitive load and/or information overload increases the risk for humans to err. Certain reasons why people make errors are we sometimes are forced to interact with technology, machines or instructions that are designed in ways that incompatible with our modes of cognition. The limited short-time memory capacity is used for remembering details that make no sense to us or (it is easier to recognize than recall), having to focus our limited attention capability on static situations or very similarly appearing displays or rows, and lack of adequate feedback. Thus people make errors, and the overall aim is to design technology etc., in ways that we are cognitively suited to and offer situations that minimize errors and high cognitive load.

HOW TO USE THE CLAM ASSESSMENT TOOL

A brief presentation of the factors USED in CLAM

This section briefly presents all the relevant factors that affect cognitive load for the assessment applicable in the interactive CLAM assessment tool. Note that the unit of analysis is on the workstation level (including both the human and his/her working environment in the unit of analysis), including the tasks and the workstation design/layout. Each factor should thus be considered by their impact on each workstation, not individual tasks. These factors are then accompanied by details and motivations of good and poor design according to the cognitive and design literature. The 11 factors identified in the assessment tool include both task- and workstation-related factors are the following ones.

Task-based factors are:

1. Saturation
2. Variant flora
3. Level of difficulty
4. Production awareness
5. Difficulty of tool use

Workstation factors are:

6. Number of tools available
7. Mapping of workstation
8. Parts identification
9. Quality of instructions
10. Information cost
11. Poke-a-yoke and constraints.

In the following chapters, each factor will be described in more detail, as well as presenting examples of good and bad solutions/design of each factor, as a guiding principle for the assessment by the evaluator(s). The involved factors, along with a brief description and a suggestion for how the factor can be measured or quantified, are presented in upcoming chapters. As an outcome of using the CLAM for assessment, a scoring interval of cognitive load is developed (with a rating scale ranging from "0" to "8", see figure 4, below.

Interval	Assessment
6-8	High cognitive load
4-6	Moderate cognitive load
2-4	Low cognitive load
0-2	Very low cognitive load

Figure 4. The different scoring levels of cognitive load in CLAM.

Procedure – individual or pluralistic assessment

The assessment can be performed either *individually* or *pluralistically*. If you want to perform it individually you just jump over the next paragraph and follow the instructions.

If you want to perform it pluralistically, this is how we suggest you should do it. The motivations for doing a pluralistic assessment are the added values of collecting several evaluators' assessments, their opinions as well as the insights gained in the upcoming discussions. The identified drawbacks of a pluralistic assessment are that it takes more time to perform, extra effort to find additional and relevant evaluators, and that several evaluators need to be present simultaneously at the same time and on the same place. The additional evaluators could be other engineers, production leaders, technicians, but also assembly workers. We suggest that 3-5 evaluators are sufficient (preferably with varying expertise), otherwise the pluralistic assessment will be too time consuming and not beneficial of bringing additional value. The pluralistic assessment is similar to the individual assessment but with the following adjustments. We recommend that one of the evaluators takes field notes or audio record the discussions or that an observer conducts this task. (1)Each evaluator assesses separately how he/she will assess the current factor. This practice is important in order to ensure independent and unbiased assessments from each evaluator. (2) When all evaluators have done their assessments a discussion begins, in which each evaluator starts to verbalize and discuss his/her assessment and opinions. If an assembly worker participates, he/she should begin. When the first evaluator's comments are exhausted then the next evaluator offers his/her assessment and opinions for the current factor. This will continue until all evaluators have provided their assessments and opinions. (4) After the discussion, you should move on to the next factor and repeat the same procedure. Thus the pluralistic assessment moves to the next step. (5) When the pluralistic assessment is completed (all the 11 factors are assessed and discussed), a general debriefing is conducted in the pluralistic team in order to discuss the obtained result (the overall cognitive load of the workstation) and the insights derived. The debriefing serves as a starting point for future work in order to decrease potentially identified high cognitive load.

The assessment is most easily conducted directly in your lap top computer/smartphone/PDA (available at http://www.clam.se). However, if you are unable to complete the assessment "online", away from the unit of assessment (i.e. the workstations at the shop floor), it is possible to print out the factor sheets, bring them to the shop floor for assessment, and then transfer the scores to the computer. The procedure for performing the assessment is based on the computer version of the CLAM tool. To perform the assessment, follow these instructions:

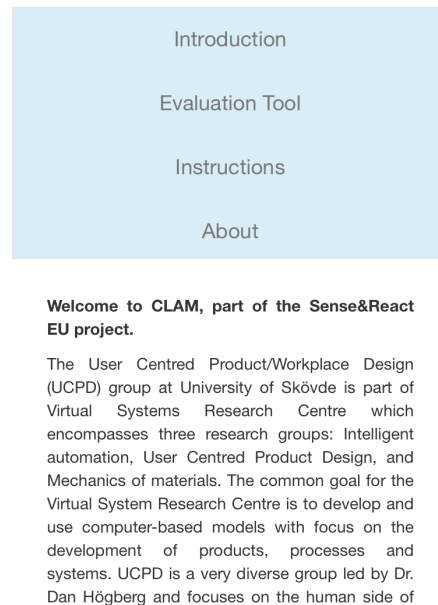1. Go to **www.Clam.se** and click on 'Evaluation tool'

Figure 5. The CLAM welcome page.

2. Read the introduction to each factor and perform the assessments

The introduction is divided into several parts; clicking the heading for each factor reveals a description where a quick introduction to the factor is given, a measurement part, which tells you in what format the "measurement" should be given, a brief description on how to evaluate the factor, and finally a description of the levels that the factor can be assessed by. Perform the assessment according to the instructions, then click the selection list and indicate your assessment. If you need more information on how the factors should be assessed, please refer to this handbook and the upcoming chapters, which deals with the individual factors.
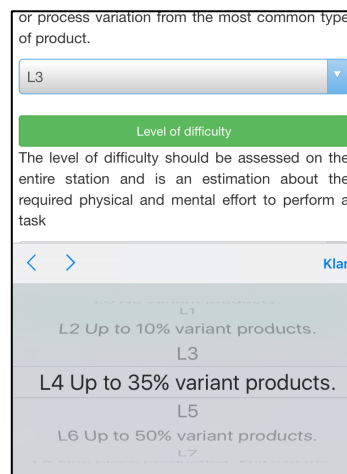

Figure 6. Assessment page of one of the factors.

The indicated levels of assessment in the instructions should be seen as guides for your assessment. Only 5 out of the 9 levels have explanations and user should feel free to translate the assessment levels to their own situation and utilize the full 9 levels should it be needed.

3. Overall calculation of your assessments of cognitive load

After the last factor has been assessed, the results will be calculated and revealed to you in the form of a number between 0-8, indicating the estimated cognitive load of the entire task. If you find that the workstation that you have assessed is associated with high levels of cognitive load and you wish to address this issue, please refer to the descriptions of the individual factors that can be found in upcoming sections of this handbook.

Weighting of factors

To avoid assigning all factors equal weight, a weighting procedure has been carried out which distinguishes the factors from each other in terms of the impact that they have on the final result. The weighting was conducted by a team heavily experienced academics and industry representatives and consisted of a pair-wise comparison (Olson, 1995) of all the factors, similarly to the procedure taken in the well-known NASA-TLX evaluation tool (Hart, 2006; Hart & Staveland, 1988). The default setup of the weights can be seen in Table 1.

Table 1. Default weights of CLAM.

	Saturation	Variant flora	Level of difficulty	Difficulty of tool use	Production awareness	Number of tools	Mapping	Parts identification	Information cost	Quality of instruction	Poke-a-yoke
Weight	0,17	0,11	0,07	0,02	0,07	0,01	0,13	0,11	0,12	0,11	0,07
Rank	1	4	9	10	7	11	2	4	3	4	7

DESCRIPTION OF THE FACTORS USED IN THE CLAM ASSESSMENT TOOL

1 SATURATION

The term 'saturation' refers to the amount of work that is planned on a workstation. For a simple example; consider a workstation within an assembly flow where the tact time is 100 seconds. If this workstation has an occupancy of 92 seconds then the saturation is 92%.

The saturation of a task or a workstation can and should be measured through time studies. Most industry have normative descriptions of how much time should be spent on each task and the comparison of this value to the balance of the workstation (the time set aside for the whole workstation), reveals a value for the saturation of each workstation.

1.1 Assessment

Description:
The saturation of a workstation is related to the particular balance of the assembly tasks. Actual work operations can rarely occupy 100% of the available time and the saturation assessment indicates how much of the available time is occupied by work tasks.

Measurements:
Percentage of planned occupied time.

How to evaluate:
Accurate time studies should be available in most SME's and larger organizations.

Levels:

Level	Description
L0	Not applicable
L1	
L2	65% saturation or lower
L3	
L4	65-75% saturation
L5	
L6	75-85% saturation
L7	
L8	85% saturation or higher

2 VARIANT FLORA

It is a well-documented fact that the variant flora does have significant effect on production efficiency and it can easily be argued that this effect relates to the cognitive workload of the assembly worker (Thorvald, 2011). However, the concept of variant is only relevant in, more or less, one-piece production where there can also be said to be a volume product. In many manufacturing companies, one does not consider variant and volume products but different types of products are instead batched together. This greatly benefits ramp up times and allows for routine work by the assembly worker, but does not, perhaps, comply with lean production, low fill rate through MTO (Make To Order) and other current manufacturing paradigms. However, considering only the cognitive workload of the assembly worker, batching can become a quality risk when batches are small and workers are expected to adjust to new batches relatively often. What would be considered a high variant flora or a small batch size is very dependent on the product and differences between variants or batches and thus this factor would have to be calibrated internally.

2.1 Assessment

Description:
The variant flora is relevant to manufacturing organizations running a mixed mode assembly flow, i.e. a flow where volume and variant products are assembled intermixed and not according to a batching strategy. A variant is defined as product or process variation from the most common type of product.

Measurements:
Percentage of products being considered variants (i.e. non-volume) products.

How to evaluate:
Assessment of what percentage of daily output is made up of variant products.

Levels:

Level	Description
L0	No variant products.
L1	
L2	Up to 10% variant products.
L3	
L4	Up to 35% variant products.
L5	
L6	Up to 50% variant products
L7	
L8	One piece production. Full variation.

3 LEVEL OF DIFFICULTY

The level of difficulty is a subjective assessment regarding the estimated difficulty that a workstation entails. To aid the evaluator in assessing this, the factor is heavily tied to the amount of time required to acquire the necessary training and skills needed for independent work. It is also very beneficial to gather opinions from blue-collar workers about the estimated level of difficulty at this workstation. As this factor is quite difficult to assess objectively, subjective opinions from both white and blue-collar workers are required.

3.1 Assessment

Description:
The level of difficulty should be assessed on the entire station and is an estimation about the required physical and cognitive effort to perform a task.

Measurements:
Subjective

How to evaluate:
Observation; the assessment is divided into eight categories where the assessment should be based on how long it would take before a recently employed worker is allowed to work alone with the task.

Levels:

Level	Description
L0	Not applicable
L1	
L2	The task requires little to no training and is recommended for newly employed personnel.
L3	
L4	The task is quite simple with little training required.
L5	
L6	The task is slightly complex and requires moderate training and experience.
L7	
L8	The task is very difficult and requires significant training and experience.

3.2 Details

In most manufacturing facilities, the level of difficulty on workstations varies to some degree. The result of evaluating the level of difficulty is highly susceptible to the inclinations of the individual assessor. Thus, the assessment is based on practice in introducing new personnel to a workstation. If a workstation requires very little or no training for new personnel, then the lower levels of assessment should be chosen. If specific training and a small degree of monitoring is required, level two should be selected. For more moderate training and experience, level three should be selected and if the workstation requires significant amounts of expertise and experience is required, then the fourth level is recommended

4 PRODUCTION AWARENESS

The attention resources of humans are very limited and thus must be considered when designing for cognitive work. This factor is focused on the amount of focused or active attention that is associated with a task through the estimation of variability of work. Note that this is not limited to the presence of variant products but is also dependant on workstation times and the longevity of the tasks performed. Fastening of dozens of bolts within the same task should be considered routine work even though the bolts might not be of the same type.

5.1 Assessment

Description:
An assessment on how much focused attention must be applied to the task and the level of "production awareness" that the worker has to muster.

Measurements:
Subjective

How to evaluate:
Observation according to levels.

Levels:

Level	Description
L0	Not applicable
L1	
L2	The assembly task is done purely out of routine and the sequence seldom changes.
L3	
L4	The assembly task is mostly done on routine but deviant parts or assemblies do occur.
L5	
L6	The assembly task is quite variable but still contains much routine work.
L7	
L8	The assembly task is highly variable and contains little to very little routine work.

5.2 Details

Attention is, along with response time and short-time memory, the most limited cognitive capacity that humans have. Specifically, focused or active attention is finite and cannot cope with too much or too similar information. A rule of thumb is that if a task can be done by routine it is not focused but passive and thus is not subject to this limitation.

To understand the concept, consider learning to drive. When you are in the learning process, this task requires very often significantly focused attention resources, but when learned, it is done automatically, on routine. Tasks that do not differ from each other in actual performance are soon automatized and do not require much attention resources whereas tasks that do differ (e.g. due to

variant flora or poor information design) require much more attention resources. If large amounts of the work can be done by routine where the same work is repeated, the assessment should be in the lower levels whereas if focused attention is required to find information, identify product variants or find tools and material, the assessment should be in the higher levels.

5 DIFFICULTY OF TOOL USE

The difficulty of tool use is assessed station wide based on accessibility and operation of a tool and is also a very subjective assessment, very dependent on the experience of the evaluator. The factor focuses on both the amount of tool use required and also on the estimated complexity of said tool use. Furthermore, the factor includes all tool use, meaning that all work not done by hand or bodily manipulation is considered here. Also, the use of special tools or non-standard tools is highly relevant.

4.1 Assessment

Description:
The difficulty of tool use should be assessed workstation wide based on accessibility and operation of a tool. If several tools are used, the assessment should be a mean of these. All tool and fixture use is included in this factor, i.e. power tools, hand tools, fixtures etc.

Measurements:
Subjective

How to evaluate:
Observation according to levels.

Levels:

Level	Description
L0	No tool use
L1	
L2	The assembly task is performed mostly by hand and requires little or very simple tool use.
L3	
L4	The assembly task contains little to moderate tool use
L5	
L6	The assembly task contains moderate tool use of some complexity
L7	
L8	The assembly task requires complex tools/tool use and/or special tools to perform

4.2 Details

The discrimination between complex and simple tool use might be difficult to assess objectively. For your assistance as an evaluator, consider the following questions:

- Does the work require any tool use at all?
- What kinds of tools are required? Is the tool use straightforward or does it require any non-standard tools?
- Are the tools adapted to the task?
- Is the same tool used for several different operations? If so, is it clear in what way the tool should be used for the different operations?

- Does the task require complex or non-standard tools where specific training is required?

Finally, try also to consider the training time normally associated with the task as this might give you a valuable clue to the level of difficulty associated with tool use.

6 NUMBER OF TOOLS AVAILABLE

A simple metric describing the number of tools used during normal assembly work at a workstation.

6.1 Assessment

Description:

The number of tools available and used on the workstation. This factor also includes fixtures and special contraptions that are used for work. If in doubt, include anything that is handled by the worker but that is not part of the product.

Measurements:

Assessment of tool availability.

How to evaluate:

Observation according to levels.

Levels:

Level	Description
L0	No tools used
L1	
L2	1 to 5 tools and easily identified
L3	
L4	More than 5 tools and easily identified
L5	
L6	5-8 tools and not easily identified
L7	
L8	More than 8 tools

6.1 Details

Tools that should be considered include both manual tools as well as power tools.

7 MAPPING OF WORKSTATION

An assessment of how well the workstation design complies with the assembly sequence. For instance, tools and parts that are used together should be placed together and in the correct order.

7.1 Assessment

Description:

The mapping of a workstation refers to the correspondence with the workstation layout to the assembly sequence. Are items and tools placed in the order that they are to be used?

Measurements:

Subjective

How to evaluate:

Observation assessment on correspondence between workstation layout and assembly sequence for common products.

Levels:

Level	Description
L0	Not applicable/the worker is free to set up the workstation and all it's components to their own preferences.
L1	
L2	Workstation layout almost completely corresponds to assembly sequence.
L3	
L4	Workstation layout heavily corresponds to assembly sequence.
L5	
L6	Workstation layout somewhat corresponds to assembly sequence.
L7	
L8	Workstation layout does not correspond to assembly sequence.

7.2 Details

The relevant parts of the workstation layout for this factor includes all artefacts, materials, or tools that the assembly worker interacts with. You should consider material racks, tools and the positioning of these, and also secondary items such as packaging materials and recycling bins, if they are regularly used. Bins and equipment that is not regularly used can be omitted. An easy way to start organizing the work regarding tools can be found in the Toyota production systems 5S (Monden, 1995), this methodology can also be used in the assessment of this factor.

There are five primary 5S phases: They can be translated from the Japanese as "sort", "straighten", "shine", "standardize", and "sustain". Other translations are possible. A selection of the factor relevant issues from 5S are:

- Remove unnecessary items and dispose of them properly.
- Arrange all necessary items in order so they can be easily picked for use.
- Make it easy to find and pick up necessary items.
- Maintain everything in order and according to its standard.
- Everything in its right place.

In a mixed mode flow, naturally it is impossible for the workstation layout to correspond completely to the assembly sequence. In this case, the assessment should be at L4 or higher.

8 PARTS IDENTIFICATION

Different types of part identification systems are more or less adapted to human use. The use of article numbers, for instance, has many benefits when used in computer systems as they are easily discriminated from each other and they are infinitely combinable. However, for human workers, they pose many challenges as their information value is limited at best. Lately, other types of parts identification and material supply solutions such as different types of kitting and sequencing of material are used.

8.1 Assessment

Description:
Parts identification can be done in several different ways. The traditional way is through article numbers and material racks but other approaches can include kitting and alternate parts identification syntaxes.

Measurements:
Selection

How to evaluate:
Determine type of parts identification system.

Levels:

Level	Description
L0	Not applicable
L1	
L2	Sequenced kits or kanban is used for most items.
L3	
L4	Unsequenced kits or kanban is used for most items.
L5	
L6	Majority of parts identification through symbol syntax or similar.
L7	
L8	Majority of parts identification through article numbers.

8.2 Details

There are different approaches to parts identification and material supply that may not fit into the level explanation provided here. If your strategy cannot be found in the level description, please do your best to translate it into a suitable level. L1 is for tasks where the worker has to do no selection of material but rather just picks the part that is in the next sequenced area. L2 is where there are some prepared kits or trays of material but the different parts for one product are bundled together. For L3, parts identification is done with some syntax that carries semantic content. For instance, using symbols or colours instead of random numbers has been shown to be beneficial to human cognitive processing. Even though the symbols or colours are not connected to the part they are referring to, the mere usage of recognizable syntax that has any meaning to the human is beneficial and easier to recognize and remember. L4 is

reserved for cases where parts identification codes are randomly generated, such as in the case of most (but not all) article numbers, in numbers or letters that have no meaning to the worker.

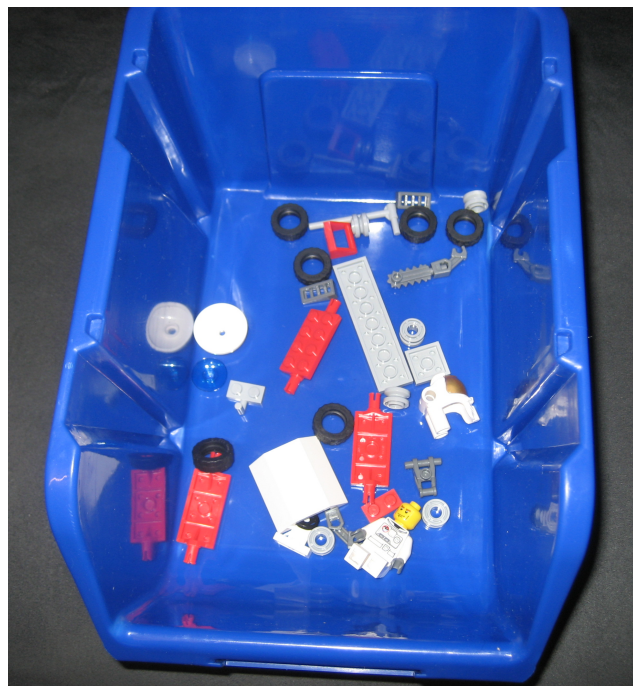**Figure 7. An example of a sequenced kit for a small LEGO assembly.**

Figure 8. The same LEGO assembly in an un-sequenced kit.

9 QUALITY OF INSTRUCTION

An assessment of the general quality of the instructions used in order to gather information about the work. There exist a lot of guidelines within the Human-Computer Interaction (HCI) area for instructions, e.g., Clark et al.'s (2006) evidence-based guidelines to manage cognitive load, Black et al.'s (1987) work on minimal instruction manuals, Carroll et al.'s (1988) minimal manuals, Mullet and Sano's (1995) design of visual interfaces, and Eiriksdottir and Catrambone's (2011) procedural instructions, principles, and examples, to mention but a few.

10.1 Assessment

Description:

The quality of instruction is a subjective measure that can be assessed according to several different factors. Focus on general visibility and readability of the instructions is recommended.

Measurements:

Subjective

How to evaluate:

Observation assessment on quality of instruction. The following points should be considered when assessing the factor:

- Text to background contrast is adequate
- Avoid dark on dark or light on light
- Font size and spacing is adequate
- If in doubt, larger font sizes are generally preferred. Also, line spacing should not be too small as it tends to make lines hard to discriminate to each other.
- Only relevant information. Manufacturing workers are often under time pressure and information that is of no use to them only slows them down in search of the relevant information.
- Reasonable time to find relevant information. This is highly connected to the assembly time and must not be excessive.
- Major tasks are clear and descriptive
- Critical content is clearly visible
- Emphasis (bold, colouring etc.) is used only where relevant, not elsewhere.
- Information is placed "above the fold". The user should not be required to scroll/turn the page on the interface/instructions.
- Labels and buttons are clear. If the interface is interactive (i.e. the user is supposed to interact with the interface) the labels and buttons must be easily identified.

Levels:

Level	Description
L0	No instructions required
L1	
L2	Assembly sequences are clearly separated and contains only relevant information
L3	
L4	Assembly sequences are separated and contains mostly relevant information
L5	
L6	Assembly sequences are not clearly separated and visibility OR readability is diminished.
L7	
L8	Instruction is filled with non-priority information. Visibility AND readability is diminished.

10.2 Details

Below is an example of quite poor instruction design. There are several different emphasis used; underlined, italics, and bold lettering. The line spacing is very varied and it is quite difficult to discriminate actual tasks from random information, not relevant to the assembly workers.

Figure 9. Example of poor instruction design.

10 INFORMATION COST

The cost of information is described as an assessment of how much physical or cognitive effort that is required to utilize the information (Thorvald, 2011). It has been both argued and empirically confirmed that the cost of gathering information has great impact on the actor's proneness to do it. Most likely, actors value the information that they believe is to be gathered from experience and make an internal cost-benefit calculation to see if the information should be gathered or if there is room for a "gamble" (i.e. making an experienced assumption on what the information contains). The factors that affect this calculation are the following:

1. The cost of gathering the information.
   a. Physically – is the information located far away from the actor or can it be attended with minimal physical effort?
   b. Cognitively – is the information structured so that a mere glance at the information medium is enough for information gathering or is extensive search through the documentation necessary to find the correct information?
2. The perceived value of the information – largely based on the frequency with which the information varies. The less the information varies, the lower the perceived value is since it is almost always the same and an educated guess is probably enough in a majority of the cases.

9.1 Assessment

Description:
The cost of information can be described as an assessment of how much physical or cognitive effort that is required to utilize the information.

Measurements:
Subjective

How to evaluate:
Determine if access to information requires physical or cognitive effort. What constitutes as a significant effort can be quite tricky to define but the general conclusion seems to be that it is less than you would think. If accessing information requires more than just a turn of the head while doing the task, it might be considered significant in certain cases. To assess this factor properly, it is highly recommended that you consult the assembly workers and get their opinions.

Levels:

Level	Description
L0	No instructions required
L1	
L2	Information is not required for standard operations.
L3	
L4	Information is no more than one step away and easily found.
L5	
L6	Information is accessible through some cognitive or physical effort (several steps or visual search).
L7	
L8	Significant movement or actions are required for information access.

9.2 Details

An academic experiment, set up to mimic truck assembly showed as much as a 50% reduction in quality defects when using a mobile, handheld information unit as opposed to a computer terminal situated about 2-3 meters away. Workers were more inclined to attend the information in the mobile unit since it was always at arm's length. They were also more inclined to go back and look a second and third time to avoid having to keep all information in their short-time memory.

Figure 10. Picture of an experiment where number of errors were reduced by 50% when using a handheld device compared to a laptop computer (stationary) for information presentation.

11 POKE-A-YOKE AND CONSTRAINTS

Poke-a-yoke is a Japanese term that means "mistake-proofing". A poke-a-yoke is any mechanism in a lean manufacturing process that helps an equipment operator avoid (*yokeru*) mistakes (*poka*). Its purpose is to eliminate product defects by preventing, correcting, or drawing attention to **human errors** as they occur. *Forcing functions* - A forcing function is an aspect of a design that prevents the user from taking an action without *consciously* considering information relevant to that action. It *forces* conscious attention upon something ("bringing to consciousness") and thus deliberately disrupts the efficient or automatized performance of a task. Using a forcing function is self-evidently useful in safety-critical work processes. It is however also useful in situations where the behaviour of the user is *skilled*, as in performing routine or well-known tasks. Execution of this type of tasks is often partly or wholly automatized, requiring few or no attention resources (controlled processes), and it can thus be necessary to "wake the user up" by deliberately disrupting the performance of the task (www.interactiondesign.org).

Figure 11. Example of a physical constraint where either ends of the USB cable has to be connected the right way.

11.1 Assessment

Description:
Using poke-a-yoke solutions or constraints in assembly is a common way to reduce assembly errors. This includes designing the task and/or the product so that assembly errors cannot be made.

Measurements:
Subjective

How to evaluate:
Determine to what extent constraints or poke-a-yoke solutions exist.

Levels:

Level	Description
L0	Assembly errors cannot be made due to the design and fit of the product.
L1	
L2	Assembly errors can barely be made due to the design and fit of the product.
L3	
L4	Assembly constraints are present in most of the assembly sequence.
L5	
L6	Assembly constraints are present but not throughout the assembly sequence.
L7	
L8	No poke-a-yoke solutions are implemented in the task.

11.2 Details

Some of the most common examples of *poke-a-yoke* are the use of;

- Guide pins – assuring that components can only be assembled in the correct way.
- Counters – confirming that the correct number of components or steps have been assembled or carried out.
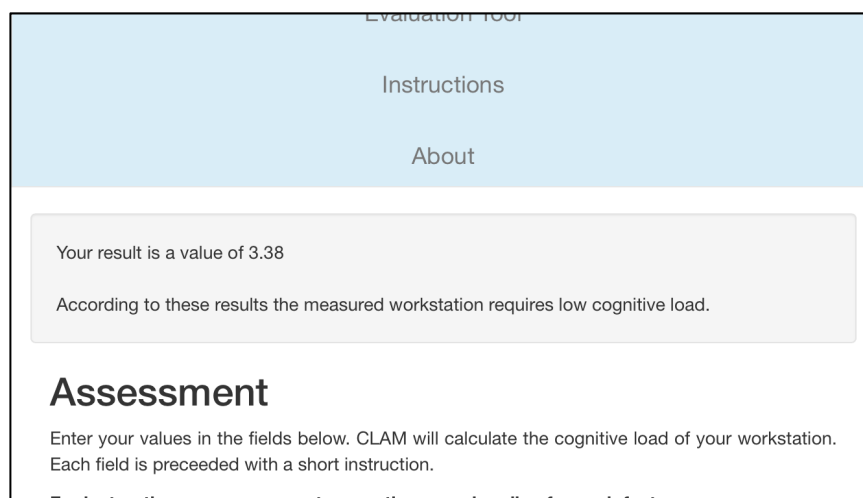- Checklists – reminding workers to perform specific actions

Figure 12. Another example of a poke-a-yoke solution. The steering wheel of a pedal car which can only be fastened in one way, thus always resulting in the correct alignment of the steering wheel.

HOW TO INTERPRET AND USE THE RESULTS AND FURTHER RECOMMENDATIONS

The calculated results of the workstation's cognitive load

When all 11 factors have been assessed and a level has been picked for each of them, the system calculates and reveals the final assessment according to the weights discussed earlier. The result from the CLAM method is an assessment of identified issues regarding cognitive load at the workstation with references to the 11 factors from the view of the evaluator. The output is presented both for each factor as well as an overall calculated assessment of the workstation as a whole (see Figure 13).

Figure 13. The assessment page of CLAM.

Some recommendations of how to interpret and use the obtained results

A shortcoming of the CLAM method is that it identifies problems with high cognitive load without providing proper detailed indications or accurate answers how they are to be fixed.

On the one hand, this may not be as negative as viewed at first glance, given the identification of too high cognitive load is a necessary but not sufficient step in order to decrease cognitive load in assembly workers. The identification of potential cognitive load problems contributes to improving the assembly workers' level of cognitive load, given that the identification of high cognitive load often implies appropriate and sometimes even obvious solutions at the current workstation and/or assembly task. Furthermore, it is not a viable approach to provide detailed recommendations of how to properly reduce a certain workstation's level of cognitive load considering the huge variations of workstation designs as well as assembly task procedures. On the other hand, the CLAM method presents several details to carefully consider when assessing the factors, and these details may serve as starting points for reducing too high cognitive load, as well as increasing the evaluator's awareness and knowledge of the causes resulting in too high cognitive load.

In the following, we present some recommendations of how to proceed when you as an evaluator have identified too high cognitive load, either in a certain factor(s)(locally) or in a majority of factors (globally).

The first recommendation for handling with high levels of cognitive load, either globally or locally, is the possibility to perform a group assessment in order to (1) double check the relevance of the obtained results of the individual evaluator, (2) conducting severity ratings (see the next recommendation) of the obtained levels of high cognitive load, and (3) considering how to handle the situation. We strongly suggest that both unexperienced as well experienced assembly workers are involved in a group assessment (or severity ratings) so they can provide additional insight given their varying levels of expertise. It is widely acknowledged that experienced assembly workers have developed certain work procedures/practices that are beneficial for the performance of certain tasks, so-called workarounds, i.e. nonaligned to prescribed work procedures but still used given their smoothness. This way of working, involving varying levels of expertise, is more cost effective than involving several assembly workers at the same level of expertise. However, it is better to include any assembly workers than no assembly workers. The trade-off in performing both individual and group assessments is time, but the added value may be additional insights and tentative solutions to reduce the high cognitive load. We suggest using three evaluators is satisfactory for practical purposes.

When performing a group assessment, we suggest that the evaluators perform their assessments (and/or severity ratings) individually, and then conduct a group debriefing of the obtained results, where they together present and discuss their individual results. This way of working is important in order to ensure independent and unbiased assessments (and/or severity ratings) from each evaluator. The result of the group debriefing should be documented and available soon after the group debriefing as support for future actions.

The second recommendation is to perform some sort of severity ratings of the obtained CLAM results. Conducting severity ratings is a viable approach to determine the most serious problems with high cognitive load, what kind of resources are needed to reduce the cognitive load, and offers a rough estimation of additional efforts to reduce the cognitive load. If the results of the severity ratings indicate many critical problems related to cognitive load is present at the workstation, there is a need to take action immediately, in order to reduce the cognitive load. Some guiding questions to use when performing the severity ratings are:

- The *impact* of the identified problem(s) of too high cognitive load, to what extent can the assembly worker overcome the cognitive load?
- The *persistence* of the cognitive load: is this an initial problem of too high cognitive load that the assembly worker can overcome as soon as the issue is made explicit or will the cognitive load still exist?
- The *frequency* with which the high cognitive load occurs, i.e., is it common or rare in the assembly task and/or the workstation layout?

The severity rating scale (a combination of the three questions raised above) could range from 0 to 4, where:

- "0" denotes this is not a problem with high cognitive load at all".
- "1" denotes "only a trivial problem with high cognitive load which does not need to be reduced unless extra resources are available".
- "2" denotes "minor problem with high cognitive load, and reducing this should be given low priority".
- "3" denotes "major problem with too high cognitive load, and it is important to reducing it and should be given high priority".
- "4" denotes " catastrophic problem with too high cognitive load, and it is of major importance to reducing, and it should be given high priority to fix this immediately"

We suggest that severity ratings from a single evaluator may be insufficient, and therefore more evaluators should judge the severity of too high cognitive load, and using the severity ratings from at least three evaluators is satisfactory for practical purposes. The use of several evaluators is also aligned with the prior recommendation.

The third recommendation is to perform some kind of a brainstorming in the end of the group debriefing session. The brainstorming should focus on discussions of possible redesigns of the workstation design and/or the assembly task in order to reduce problems identified with too high cognitive load. It should also be mentioned that the group debriefing is a great opportunity for discussing and documenting the good examples of how to reduce cognitive load is obtained in the workstation design and in the assembly task, since good examples are of importance to address, both for preservation as well as inspiration for reducing too high cognitive load.

The fourth recommendation concerns what you can do at once, when too high cognitive load is identified. Some initial steps are not allowing an assembly worker to be placed too long time at an assembly task and/or assembly station with high levels of cognitive load. We also suggest the use of job rotation as well as increasing the frequency of breaks in relation to high cognitive load. The assembly workers' level of expertise should be considered.

The fifth recommendation is to hire a consultant from either academia or industry whom has a relevant specialization in cognitive aspects/human factors/applied ergonomics for reducing high cognitive load in assembly tasks and workstation design in manufacturing.

The final recommendation is to read more about the aspects of high cognitive load and the underlying causes, see the suggested list of readings at the end of this section.

On a final note, as this evaluation inherently will be influenced heavily by who performs the evaluation, please consider this advice:

- *If a redesign of a task or workstation has happened as a result of a CLAM evaluation, the same evaluator who identified the problem initially, should be the one doing the follow up evaluation. This is to ensure a reliable and equivalent assessment.*
- *If possible, always aim at performing the assessment in a group of at least three evaluators to eliminate major individual differences.*

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