Cognitive automation in assembly systems for mass customization

Fässberg,T., Fasth, Å., Mattsson, S., Stahre, J
Chalmers University of Technology, Department of Product and Production Development, Division of Production system, Gothenburg, Sweden
tommy.fassberg@chalmers.se

ABSTRACT

Manufacturing industry is struggling with high demands on mass customization, shortened product life cycles, and consequences of globalized production. Further, new products must address sustainability factors, which adds to the complexity of production and final assembly systems. Product developers as well as assembly operators must deal with emerging information and communication needs. This will require new cognitive ergonomic design solutions regarding presentation and communication of information to and from operators in final assembly.

This paper describes a case study in a manual assembly context, within the Swedish automotive industry. The aim was to examine how information flows affects operators working in mixed-model assembly systems. Information and communication flows were mapped and task allocation assessments, including measuring and analysis of cognitive levels of automation, were made.

Results indicate a need to increase cognitive automation, to better support assembly operators. This can be accomplished through task-based information, presented when and where the operator needs it. In this case solved by presenting qualitative information on a mobile communication device. The proposed solution will reduce perceived complexity, adding to the flexibility of final assembly in future assembly systems mass customized.

Keywords: Assembly Systems, Cognitive Automation, Task based information

1. INTRODUCTION

In modern production mass customization is the dominant paradigm to achieve highly personalised products [1]. This way of producing puts high demands on manufacturing industries with demands on shorter product life cycles and high degrees of flexibility [2, 3]. An increasing number of customers require highly customized products due to their needs, e.g. design, function, and lifestyle. Also, new products addressing sustainability issues, e.g. hybrid engine vehicles, further adds to the complexity of future production and final assembly systems. Emerging requirements put great strain on product developers as well as on assembly operators, especially in terms of information and communication needs.

Product variation driven by mass customization creates a vast need of information to support the assembly operators' working in final assembly. Therefore better information flows are required to support personnel operative in a mixed-model environment. Further, a vast variety of products increase the perceived complexity for operators in final assembly environments. It is argued that flexibility and complexity may be in conflict, meaning that the more flexible a manufacturing system is, the more options are available, which may lead to a higher degree of complexity [4]. Slack [5] argues that all resources can contribute to flexibility, but that technology cannot be fully effective without flexible operators and vice versa. Therefore, appropriate Levels of Automation (LoA), both mechanical and cognitive, need to be selected to ensure systems that support demands driven by mass customization. An increased cognitive LoA (i.e. more decision-making tasks are performed automatically) could improve the operators' work situation and decrease their workload while retaining the same mechanical automation [6]. It can be expected that sustained attention, problem-solving, planning and reasoning skills will be needed in future assembly systems rather than physical strength or dexterity [7]. Already, extensive amounts of work in existing manufacturing systems are related to information rather than products [4]. This motivates a shift of focus from mechanical towards cognitive automation. Nevertheless, many system designers are focused on the physical system [8] when aiming towards a more flexible assembly [9], but both physical and cognitive need to be considered.

The objective of this paper is to propose a design of an information and communication system for assembly system operators, in order to reduce perceived complexity, caused by mass customization manufacturing. The paper focuses on how cognitive levels of automation and task based information influences final assembly.

An industrial case is presented, were content and carrier in the information system have been altered in order to increase the cognitive level of automation, thus reducing perceived complexity and improving internal quality.

2. THE RELATION BETWEEN TASK-BASED INFORMATION AND COGNITIVE AUTOMATION IN ASSEMBLY SYSTEMS

This chapter will present the theoretical framework of this paper.

Mass customization

Diverse customer needs must be supported and managed by manufacturing companies, since a transformation from “markets of many” to “markets of one” can be seen [10]. To cope with this change, new production philosophies are needed and the dominating paradigm is mass customization [1]. The product differentiation caused by mass customization does often occur in a final assembly environment and this differentiation requires a high degree of flexibility [2].

Flexibility

Research proposes a broad range of flexibility types related to manufacturing systems. As shown by ElMaragy [11] who presented a list with 10 different types of flexibility namely; *machine, material, operation, process, product, routing, volume, expansion, control program and production flexibility. As can be expected, several* of the concepts are interrelated.

Manufacturing systems with flexibility focus have been of interest for a long period of time. Several different manufacturing systems have been proposed i.e. Flexible Manufacturing Systems (FMS) [12], Flexible Assembly Systems (FAS), Mass customization [10] and Reconfigurable Manufacturing Systems (RMS) [12].

In this paper, flexibility is mainly referred to as product flexibility (mixed-model) and resource flexibility or mobility of assembly operators. It will be measured in terms of number of products and product variety, number of tasks, and cycle time.

Complexity

Complexity was defined by Weaver [13] as the degree of difficulty to predict the system properties, given the properties of the systems parts. Schleich means that a driver for assembly system complexity is the high variety of products and parts [14]. The complexity in mixed-model assembly caused by the high levels of variety is by Hu called “choice complexity”, which concerns all choices that the assembly operator can make and the risk for error associated with these choices [15]. To meet requirements from mass customization, many assembly systems are using a mixed-model assembly approach as an enabler for the high variety of products. Although mixed model assembly is an enabler for high variety, such systems tend to get very complex as variety increases [15].

An important aspect of complexity is the “perceived complexity”. From an operator point of view this is a subjective factor such as competence and information [16]. Cognitive help tools are seen to reduce the perceived complexity by supporting competence and information. Urbanic and ElMaraghy presents a model of complexity were quantity, diversity and content of information is direct associated with complexity [17]. The focus in this paper is the complexity related to mass customization i.e. caused by an increase of number of products and parts to assemble.

Assembly Systems

An assembly system can be characterised as a system joining parts together into subassemblies or finished products [18]. The assembly process is often the final stage of the production process, which implies that the product have a lot of accumulated value hence making errors expensive at this point in the product life-cycle. Further, it is often in the assembly systems that the diversity of products is created.

Manufacturing systems can be given hierarchical descriptions where every system is divided into elements [19]. These elements can be further divided into tasks. Wiendahl *et al* shows a similar view of a manufacturing system, seen in figure 1, ranging from Network to station [12]. The focus in this paper will be on the lower sections of this model, where the information system will be handled in the working area and the cognitive automation is on working place level.

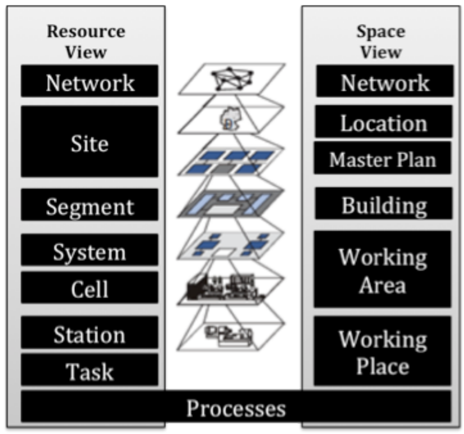

Figure 1. Structuring levels and views of a factory [12], edited by [20].

The Role of information in assembly systems

Information systems in an assembly context should aim to support operators to produce the right amount of products at the right time to the right quality thus reducing the perceived complexity. However, to design such information systems is not a trivial task. According to Kehoe it is the quality rather than the quantity of information that is of importance [21]. Six qualitative criteria for information to be received efficiently are presented: relevance, timeliness, accuracy, accessibility, comprehensiveness and format. Similar reasoning can be found in Endsley’s information gap theory claiming that more data does not result in more information [22]. Further, she states that the problem with today’s system is not the lack of information rather to find what is needed when it is needed [ibid]. Consequently, quality is obtained by providing the right information (what), at the right time (when), in the right way (how) [23].

It is important that information is presented in a way that considers the different possible roles of an assembly operator. According to Rasmussen, operators act based on three kinds of behaviour i.e. Skill-, Rule- or Knowledge-based behaviour. This model is known as the SRK-framework [24], meaning that human behaviour is dependent on the attention and competence of the operator. Thus, different levels in the framework put different requirements on information, or cognitive support. This implies that how to best support operators with information to avoid human errors is very difficult, since information and feedback must be adapted to fit individual operators. The operator must be considered with regards to both competence and situation or context. The assembly operators' needs and demand for information were discussed by Case *et al* [25] using four different situations, as illustrated in table1.

Table 1. Evaluation of need and demand of information, adapted from [25]

Information	Need	No Need
Demand	Preferred situation -Low risk for errors due to lack of information -Information matches the need	Can be frustrating for the operator -Identified a need and have a demand. -Not provided with the information that is perceived to be needed.
No Demand	An error will eventually occur. A solution might be to introduce a trigger to create a demand.	Can be frustrating for the operator. -Too much information or "wrong information" -Hard to see the vital information

In order to give feedback in an effective manner the design of attention-triggers are important. Bäckstrand *et al* found used attention-triggers to information searching (create demand) had positive effects regarding the internal quality [26]. Noting also, that it is important not to over-use triggers since there is a risk that they can be ignored.

The information system can be represented as a system with two parts; content (what) and carrier (how), see figure 2. The effectiveness of an information system can be altered by manipulating these two parameters e.g. changing how information is presented. For instance, reduced content has been shown to have an effect on internal quality in assembly operations [26]. Further, Thorvalds *et al* [27] showed that quality can be greatly improved when information is provided by a mobile information source i.e. change in carrier of information. The same study also found indications of improved productivity.

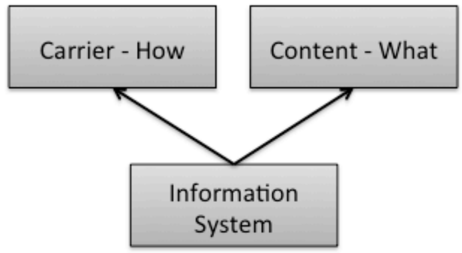

Figure 2. Information system concept, adapted from [6]

The role of cognitive automation in assembly systems

The assembly process can be manual or automated; however, due to high requirements on flexibility, many tasks in final assembly systems are performed manually. How to best allocate tasks between humans and automation is a well-studied research area and several allocation models have been proposed. Fasth and Stahre presented a concept model [6] for measuring and analysing LoA were the information system is acknowledged as an import part of the system. Further, they [ibid] stated that an increased cognitive LoA could improve the operators' work environment and decrease their workload. When companies redesign their system, they often consider mechanical LoA, while the cognitive LoA is left to be solved afterwards. Further, there is a tendency in manufacturing companies that when the mechanical level of automation decreases so does the cognitive level [28]. Several case studies have shown that several tasks in final assembly have a low mechanical and cognitive automation [ibid]. This implies that information support could be insufficient for operators in final assembly contexts.

Indirect and direct measurable parameters

In order to determine a change in an assembly system, two types of parameters could be described; indirect and direct measurable parameters. The indirect measurable parameters could be described as qualitative parameters, in this paper flexibility and complexity. The direct measurable parameters could be described as quantitative parameters i.e. time parameters, number of products, number of tasks etc. These parameters will also be related to the cognitive LoA [29].

3. METHODOLOGY

In order to determine an appropriate task allocation with a span of various levels of automation in assembly operations a methodology, DYNAMO++, was developed and validated [30]. The method consists of four phases; pre-study, measurement, analysis and implementation. The first two phases focuses on the current system while the two latter are associated with the design of a future state.

During the pre-study the system's triggers for change are identified i.e. why does the company want to change? Further, information is gathered regarding production flow and information system. Then both the LoAs are assessed in accordance with Frohm's seven-level taxonomy, ranging from totally manual to totally automatic [31]. Based on this suggestions for an improved future state are made and implemented. In this case the implementation phase consists of a pilot study aiming towards an increased cognitive automation.

In addition to the DYNAMO++ methodology semi-structured interviews and information flow mapping were used, in order to understand prevailing needs for better task-based information. The new information system was designed based on the current state analysis and the concept was to change the information content and carrier in order to increase the cognitive automation of the system. The implementation was analysed using video recordings and a workshop.

4. RESULT FROM INDUSTRIAL CASE

This section presents the case carried out within the automotive industry, were both the content and carrier of information was adapted in order to enhance cognitive automation.

Analysis of current state

Two assembly and control stations from two different final assembly lines were analysed [32] using DYNAMO++ in order to get a comprehensive image of the system. The trigger for change, from a company point of view, was the directly measurable parameter internal quality. Since the present error rate related to assembly mistakes was considered to be too high, much unnecessary work was done.

The LoA measurement showed low values (1) for cognitive automation (LoA info), as seen in figure 3. This was due to the fact that available assembly instructions were left unused and that operations were performed primarily in a skill-based fashion. Interviews revealed that too much information was presented, causing instructions to be ignored. The operators also requested more pictures and better information regarding upcoming products to assemble.

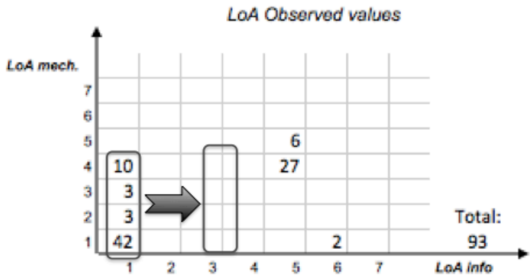

Figure 3. Future state increased cognitive LoA by adopting content and carrier of information.

The information mapping showed that there existed redundancy in the information system with risk of ambiguity of whom to communicate what with [32].

The perceived choice complexity caused by many parts and variants in the final assembly were to some extent handled by the use of pick by light for tools and scanners to secure the assembly process. It is worth noting that pick-by-light was not used for material bins, only for tool sockets.

Implementation of pilot towards the future state

A concept for a mobile ICT tool was constructed based on a thin client philosophy and realised by the use of iPod Touch as platform [33]. The tool was anticipated to increase cognitive automation by changing both content and carrier of information. The content was expanded with support for pictures, video and communication channels. Further, the level of abstraction of the text based instruction could be adjusted to fit individual requirements. Triggers to attention were introduced in form of vibration; in the test study it was used when a part with a history of quality defects were to be assembled. A preview function presenting the next three upcoming products was introduced and the carrier was changed from fixed screens to mobile units using an iPod touch attached to the operator's forearm.

The developed ICT tool was tested on four operators assembling 10 products each, which represented approximately one hour of production. Observations indicated that the operators' information searching behaviour had changed. The device was used in situations were no information searching had previously been observed for example the device was used during the use of screwdrivers and when picking up products from material bins.

Semi-structured interviews with the operators revealed that the device felt natural to use and that no discomfort was perceived. During a latter workshop, it was stated that the information presented could be further reduced but that more detailed information should be available if requested. It was also stated that triggers are needed but should be individual.

With the ICT tool implemented, a movement on the cognitive axis in the LoA matrix was obtained, as seen in figure 3.

5. DISCUSSION

Mass customization cause complexity issues for operators in final assembly environments. Every variant and every part needs to be correctly identified and assembled which requires cognitive support. Improved information support is believed to be a part of the solution to reduce the perceived complexity. By having both content and carrier in mind when designing task based information systems better information quality can be obtained hence better performance

In the industrial case, current information systems did not fully reach their potential since information was not fully used. This resulted in low values for cognitive LoA in the current state analysis. The operators stated that one reason for this was that too much information was presented. The operator only needed a small portion of the information causing a need to filter the information given. This is consistent with theory, arguing that if the quality of the information is low than it looses its value.

The operators requested a decrease of content, which is consistent with previous case studies showing that increased quality of production can be obtained with reduced content. From an operator point of view the only information needed was information that was product specific. This would reduce the need to filter information. However, additional information must be available if requested in order to support different competence levels and behaviour roles. This implies that individual task based information can be combined with more quantity of content. But the additional information should be pulled rather then pushed in the latter case. The possibility to include pictures and movies does not only add support for different competence levels and behaviours related to challenging situations, it also reduces the need to have detailed instructions in binders that easily becomes obsolete.

A change of carrier caused a change in the behaviour of the test subjects. The mobility made it possible to get instruction in situations where it previously was hard to obtain information. One example is that the device was used when operator was faced away from the product while getting material from the material facade. This means that errors related to choice complexity could be reduced. It is believed that mobility will have even more impact on stations with a lot of movements.

It is very important to design according to operator requirements. If benefits are not apparent there is a risk that automation will be unused and its benefits will be lost [34]. Therefore, it is of great importance that automation is implemented based on real needs and with the human in focus, which is possible with the use of the Dynamo++ method. This case has had the focus that every task needs to be supported and have increased the cognitive automation by providing task-based instructions with improved content.

The generalisations of these results are limited by the small sample of test persons (four) and the short period of time that they pilot was tested during (one hour per operator). This made it hard to measure if the internal quality or productivity was improved during the pilot study.

Further, tools such as pick-by-light increase cognitive automation and are used to handle complexity caused by mass customization. The reduced flexibility and cost of such systems may prevent implementation of cognitive tools. ICT technology similar to the one described in the paper should be seen as an enabler, to relatively easy increase cognitive automation and to support operators in increasingly complex assembly systems. The case is an example of how new technology has the possibility to reduce previous obstacles to present information at the right place at the right time in an assembly environment.

How a change of cognitive LoA effects direct and indirect measurable parameters is of interest, since it gives an idea of what to expect when increasing the cognitive levels of automation in the system. A projection of the change can be made into the future. In this paper we have discussed how the two indirect parameters complexity and flexibility can be reduced and increased by altering cognitive automation. The increase of cognitive automation aimed to reduce the direct parameter quality, which shows the interrelation of these parameters.

6. CONCLUSIONS

Companies have a tendency to mainly focus on mechanical automation. But in mass customized assembly systems the cognitive automation needs to be acknowledged and increased in order to handle the increased information flow to the operators.

By altering carrier and content of information cognitive Levels of Automation can be increased, thus making information more easily accessible and desirable. A mobile carrier of information is favourable to fixed screens in a final assembly environment since it is more flexible and more accessible. Information content should be designed to fit the end user reducing the need to filter redundant information and it is seen that the quality of task-based instructions has an impact on the internal quality of an assembly system. Our final conclusion is that perceived complexity can be decreased by the use of a better designed information system, considering both content and carrier. Further, that cognitive automation can be used in order to better design information on a task level

7. ACKNOWLEDGEMENT

The authors want to express their deep gratitude to researchers and industries that participated in the case study and to the project My-Car. This work has been carried out within the Sustainable Production Initiative and the Production Area of Advance at Chalmers. The support is gratefully acknowledged.

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