MANAGING PRODUCTION COMPLEXITY BY SUPPORTING COGNITIVE PROCESSES IN FINAL ASSEMBLY

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Abstract: Managing production complexity in final assembly includes understanding and supporting the operators cognitive processes. In this paper three models for information handling and decision-making are combined to better describe intuitive processes in this context. The combination form a conceptual model that was tested using two case scenarios. The scenarios show that by supporting cognitive processes e.g. by simplifying information and presenting it in a better way, production complexity could be better managed, thereby increasing operator performance and satisfaction.

Keywords: Cognitive processes, final assembly, production complexity, management

1. INTRODUCTION

Managing future production systems includes successfully managing the interactions between humans and technology (ElMaraghy, ElMaraghy, Tomiyama, & Monostori, 2012). In todays systems it is difficult to find the information (due to information overload) and the operator is therefore less informed than before (M. R. Endsley, 2000). Klein, Woods, Bradshaw, Hoffman, and Feltovich (2004) suggested that problems seen in human- automation interaction arise because the support of interaction and coordination of human and machine has become secondary. To support interaction in this context is therefore increasingly important (Galster, Bolia, & Parasuman, 2002; Lee, 2008; Sanchez, 2009). Managing complexity is connected to improving the operator performance i.e. to decrease process errors, achieve high quality, achieve good working conditions, fast processes, quick change-overs and to decrease cost (Heilala & Voho, 2001; Papakostas et al., 2010; Schleich, J, & Scavarda, 2007).

To support interaction and optimize performance it is important to understand operator's cognitive processes (J. Rasmussen, 1983). Cognitive processes are the mental processes in which humans become aware of and process information (Osvalder & Ulfvengren, 2009). Cognitive processes can be divided into two types: *intuition* and *reason* (Hollnagel, 1997; Passer et al., 2009). Chase and Simon (2013) defined *intuition* as recognising patterns already stored in the memory (came from analyzing chess players) or association (Hollnagel, 1997) while *reasoning* is connected to more effort, motivation and concentration. In final assembly the task of assembling a component is mainly connected to *intuition*.

1.1 Scope

Due to that little research has been found that specify which cognitive processes that are relevant in the production context, and especially in a final assembly context, the aim of this paper is to further describe how intuitive cognitive processes can be better supported (thereby also reducing complexity). The following question is investigated: *How can intuitive cognitive processes be identified and characterized in complex final assembly?* The question is answered by combining three models for information handling and decision-making:

(1) The Skill/Rule and Knowledge-based behavior - model (SRK-model) (Rasmussen, Pejtersen, & Schmidt, 1990; J. Rasmussen, 1983)

(2) The 'System1 and System2'-model (Kahneman, 2003; Kahneman & Fredericks, 2005)

(3) Situation Awareness (M. Endsley, 1995; M. R. Endsley, 2000)

Due to that the models, by themselves could not answer the question (see section 3), an hypothesis is that a combination of the models, describing somewhat different aspects of the cognitive processes involved can be used. Two case scenarios are presented in the discussion in order to test the usefulness and application of the combined conceptual model.

2. MANAGING PRODUCTION COMPLEXITY

To be able to optimize human performance, information given to the human should be arranged so that it fits the operator's cognitive processes (J. Rasmussen, 1983). Complexity in a system can be defined as something that is "*difficult to understand, describe, predict or control*" (Sivadasan, Efstathiou, Calinescu, & Huatuco, 2006) which is directly coupled to cognitive processes e.g. how a person understands a situation and process information. Information should not be used to support a detailed data processing, but instead support the possible behavioural characteristics used and tasks should be described in terms of mental models instead of system requirements (J. Rasmussen, 1983). Instructions that are developed without consideration of these processes can cause unnecessary cognitive load and lead to poor operator performance (Kahneman, 2003). Consider the following example: An operator assembles products on a final assembly line. At this line all types of variants are assembled at the same line, and due to that many different products are produced at the same line there are many different components connected to each variant and could be considered complex. An uncommon variant arrives just after the operator has finished a time-consuming tricky variant and there is little time for s/he to prepare for the uncommon variant. Even though there is information available in a binder (meters away) there is little time for the operator to first go to the binder, find the information and then consider it without stopping the whole line. In addition, the operator notices that the uncommon variant is connected to uncommon components. Since each component has long numbers it takes time to find the correct one before placing it on the product. Therefore the information is presented to the operator in a way not supporting his or her needs in that particular situation. Because it is how a person understands a situation, not what it objectively is, that governs his or her actions (Hollnagel, 1997). This action will in turn have an impact on their performance.

Production complexity can be managed by *removing, simplifying, avoiding* or *preventing* complexity (Corbett, Brocklesby, & Campbell-Hunt, 2002; Kaluza, Bliem, & Winkler, 2006; Wiendahl & Scholtissek, 1994). In the context of final assembly it is often not possible to *remove* production complexity due to market demands. One possibility is instead to *simplify* and thereby *reduce* complexity (Wiendahl & Scholtissek, 1994). If the information needed could be presented to the operator in a more *simplified* way the operator could save time while at the same time increasing performance. This means that the complexity at the station can be *reduced*. This was seen in an experiment were information was *simplified* so that operators could more easily interpret information (G. Bäckstrand, Thorvald, De Vin, Högberg, & Case, 2008). The effect was that operators could better prepare for new product variants both physically and mentally and an increase of operator performance was seen (reduction of assembly errors) (Ibid.).

3. COMBING THREE MODELS

To answer *how intuitive cognitive processes can be identified and characterized in complex final assembly* one model was proven useful, namely the skill, rule and knowledge-based model developed by Rasmussen. Although tested in several contexts (e.g. (Bruch, Karltun, & Dencker, 2008; T Fässberg, Fasth, Mattsson, & Stahre, 2011; Lin, Yenn, & Yand, 2010; Phipps, Meakin, & Beatty, 2010)) it was found that the SRK-model was not extensive enough to be used to answer the research question. One lack of the model is an extensive description of the intuitive processes and therefore Endsley's model of Situation Awareness (SA) was included. Due to that one criticism of the SA model is that it is difficult to identify and separate the processes in practise (Fasth & Stahre, 2013; Wickens, 2008) also Kahneman's model for two dual-processing systems was used. The three models are commonly used to describe behavior in information handling and decsion-making and includes both automatic and controlled processes which is an important aspect of both intuitively understanding a situation (has to be fast and automatic) and solving a problem (active reasoning) (Gunnar Bäckstrand, Vin, Högberg, & Case, 2006).

The chosen models are described below. Due to that the aim is to describe only *intuitive* processes, aspects regarding *reason* is limited (the reader is advised to visit the referenced papers for a detailed description of the models). It is proposed that the models intuitive parts could be combined to form a new combined conceptual model (section 3.4). Each model is presented with a figure, made by the author, where the boundary between *intuition* and *reason* is visualized (this is not explicit in the actual models). As part of the analysis, the author also identified active cognitive processes and how those processes are characterized.

3.1. The Skill-/Rule- and Knowledge-based Model (SRK-model)

The SRK framework or taxonomy was developed by Rasmussen to determine how information should be presented by considering human perception and cognitive abilities (Vicente, 1999). *Skill-based behavior* is behavior that is unconscious, and it takes very little control to perform or execute an action once an intention is formed. Performance could be described as; smooth, automated, and consists of highly integrated patterns of behaviour (Rasmussen et al., 1990). For example, bicycle riding is considered a skill-based behaviour in which very little attention is required for control once the skill is acquired; it is also often referred to craftsmanship. This automaticity allows operators to free up cognitive resources, which can then be used for higher cognitive functions like problem solving (Dickens & Hollands, 1999). This level could also be refered to as fast and depend on signals i.e trafic light (J. Rasmussen, 1983). *Rule-based behavior* behavior is characterised by conscious state recognition and access to stored rules from past work scenarios (Schlick, 2000). This type of behavior is activated by signs in the environment (J. Rasmussen, 1983). Signs, compared to signals, are instead a state in the environment that is connected to a certain behaviour. Signs are not directly processed but needs to be activated.

Knowledge-based behavior is conscious acts that occur when faced with an unfamiliar situation. This behavior is connected to trial and error or thinking conceptually. Knowledge-based behavior is driven by symbols which are abstract information, variables or properties that must be processed. A delimitation of this type of behavior is that humans can only focus their attention on few things at the time i.e. complex envrionment or causal relationships must be sequentially processed. This means that complex thinking is not prefered, since it is cognitively demanding (J. Rasmussen, 1983).

	Intuition		**Reason**
Part of model	Skill-based behaviour	Rule-based behaviour	Knowledge-based behaviour
Cognitive processes	Forming characteristics	Confirmning, connecting tools to	Identifying, deciding, selecting, planning
Characteristics	Unconscious, fast	Unconscious/conscious	Conscious effortful
Activated by what type of information	Signals	Signs (not directly proces-sesd but activate a pattern of a stored behaviour	Symbols i.e. abstract information, variables or properties that need to be processed

Fig. 1. SRK-model described by seperating intuition from reason.

3.2. Situational Awareness

The objective of the model for Situational awareness is to suggest design changes to support decision making in complex situation (M. Endsley, 1995). It incorporates the perception of elements (Level 1), the comprehension of those elements (Level 2) and the projection of a future state connected to operator goals (Level 3) (M. R. Endsley, 2000). Level 1 is connected to the perception of things seen in the environment (M. Endsley, 1995). At Level 2 these objects are combined to create a comprehension of that situation. This level therefore are involved with understanding how important specific objects are and how they can be used to achieve the operators goals. A difference in experience levels could be seen where both a novice and expert sees the objects in Level 1 the same way but have a different understanding of the situation (Level 2)(Ibid.). Level 3 is connected to being able to predict future system states - projection. This can only be done by gaining knowledge of the objects in and their dynamics (both Level 1 and 2) which mark a skilled expert (M. R. Endsley, 2000). Situational awareness is limited by a persons indvidual experiences and interests about also the capacity of the working memory (M. Endsley, 1995).

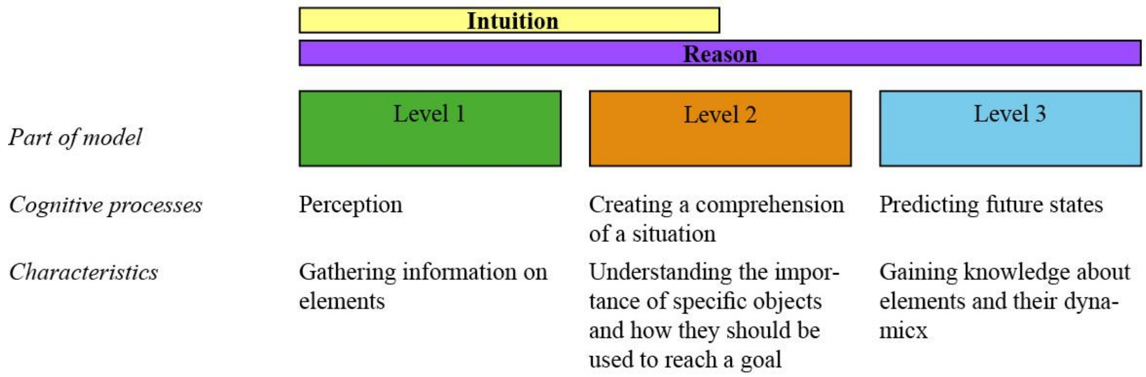

Fig. 2. Situation awareness - model described by seperating intuition from reason.

3.3. System 1 and System 2

Kahneman's model of System 1 and 2 regards the two types of cognitive processes (Kahneman & Fredericks, 2005). The names of the two systems (1 and 2) came originally from Stanovich & West (2006). The systems are divided based on speed, degree of controllability and content. *System 1* is the primitive thinking. It is automatic, effortless and fast. System 1 correlates with general intelligence, it is known as the rational system because it reasons according to logical standards (Tsujii & Watanabe, 2009). System 2 is evolutionarily recent and specific to humans. It is also known as the explicit system, the rule-based system, the rational system, (Evans, 2003) or the analytic system (Tsujii & Watanabe, 2009). The content included in System 1 thinking is affective, specific and includes causal relations. System 2 is controlled, effortful and is slow. This system acts in conjunction with System 1, and is included in complex cognitive operations such as judgments and attitudes (Kahneman, 2003). The content that System 2 operate is neutral, statistical, abstract and includes data sets. Both systems can operate at the same time but compete to control the open responses. System 1 is connected to the intuition (introduction) and the first and instant recognition of a situation whereas System 2 handles deliberate judgements (Ibid.).

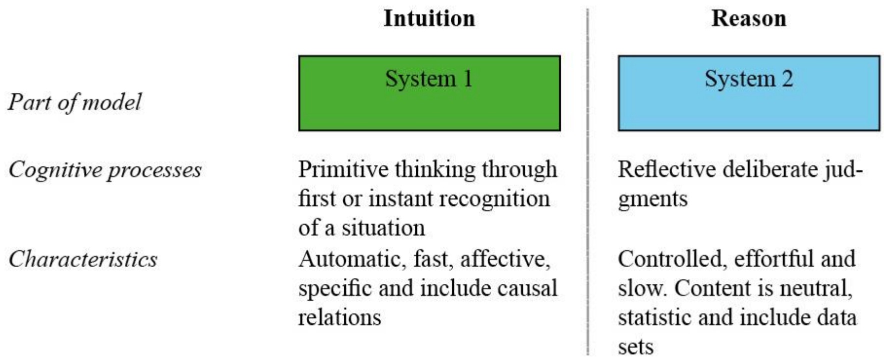

Fig. 3. System 1 and 2 -model described by seperating intuition from reason.

3.4. Intuitive processes and their characteristics – Forming a combined conceptual model

The three models are summarized in Table 1. Due to that cognitive processes in final assembly can be seen as *intuitive* the cognitive processes are, fast and occur effortlessly and mostly unconscious (intuitive processes could be conscious like for instance information searching). Considering first the assembly of a component, skill- and rule-based behaviour and System 1 could be used to describe this. An example of a *signal* in this case be a product arriving to the assembly station that activate a stored behaviour. Also *signs* (in instructions) are connected to a stored pattern of behaviour (like a using a specific tool). As this is automatic, the behaviour in daily assembly is connected to Kahnemans' System 1. In the assembly objects are identified (Situation awareness Level 1) and to some extent they may be comprehended. For instance a number of objects: instruction, components and tools are combined to assemble something. When studying situation awareness, Level 1 and 2 should be used when comprehending the elements in the operators' environment. Therefore there could be two levels describing the intuitive processes in final assembly. These processes are used when finding information to assemble an uncommon variant. This requires more effort, could take longer time but should also be fast. This behaviour therefore can include rule-based behaviour that is activated by signs (stored behaviour). Considering Kahnemans' model of systems System 1 is used due to that the task should be effortless and fast. As stated from a situational awareness perspective objects should be both perceived and comprehended to solve also minor disturbances. Figure 4 depicts a combined conceptual model that was formed based on a combination of the three models. *Level 1* can be seen as a combination of skill-based knowledge, SA Level 1 and System 1. The cognitive processes involved in *Level 1* is gathering information and recognizing elements in a situation. *Level 2* can be seen as a combination of rule-based behaviour and SA Level 2.

Intuition

Part of model	Level 1	Level 2
Cognitive processes	Gathering information, forming characteristics, recognizing elements in a situation	Comprehending a situation, understanding the importance of objects and how they can be used to reach a goal
Characteristics	Unconscious, automatic and fast	Unconscious/conscious, fast/moderate and include causal relations
Activated by what type of information	Signals	Signs

Fig. 4. Combined conceptual model describing two levels of intuition.

4. DISCUSSION

The aim of this paper is to answer *How can intuitive cognitive processes be identified and characterized in complex final assembly?* Due to that the models by themselves could not be used to answer the specific questions a hypothesis was that they could be combined. The question was therefore answered by combining the three models thereby identifying the processes and its characteristics (see Figure 4). The benefit and limits of combining the three models are discussed below.

Managing complexity in a final assembly context can be done by using both Rasmussen's model of *skill*- and *rule-based* behaviour to describe *intuition*. There is a strength in using this description due to that these behaviours are linked to how information is processed and connected to memory and mental models. In addition, the description include how these behaviours are activated (J. Rasmussen, 1983), which can be used to better present information. Information not activating these behaviours should be excluded. The SA concept is useful in order to understand how to better manage complexity in final assembly. Although it is difficult to separate and identify each level (Fasth & Stahre, 2013; Wickens, 2008) in practise the description of how a person understands a situation (Hollnagel, 1997) is important in better supporting it. Level 1 and 2 (from the SA-model) can be used to describe the cognitive processes where information can be *simplified* by supporting the operator on Level 2 by providing relevant information. Kahneman's System 1 provides further details of the cognitive processes active in final assembly. By being able to further describe the links and the *intuitive* judgments it is possible to better manage complexity by supporting the operator to stay in System 1 (instead of providing information in a way that must include controlled or effortful thinking).

Other models were not investigated which means that the model cannot be seen as a comprehensive view of all active cognitive processes. Also the combined conceptual model does not involve a deeper description of the active cognitive processes. However, as a first step the model may be detailed enough to suggest improvements in case scenarios and serve as a basis for future work.

4.1. Testing the usefulness of the combined conceptual model

To optimize human performance studying real-life cases is crucial in order to identify cognitive strategies as well as individual preferences (J. Rasmussen, 1983). Therefore studying two case scenarios could test the usefulness of the combined conceptual model. The case scenarios were previously performed within the research group (both scenarios were performed by students, the first one supervised by S. Mattsson the second one by Å. Fast-Berglund. Both researchers were part of collecting and analysing the results).

The first case scenario describe how information flow was improved by interviewing 60 undergraduates assembling Lego-gearboxes (see Li, Landström, Mattsson, and Karlsson (2014); Söderberg, Johansson, and Mattsson (2014) for more details regarding the study). Interviews showed that respondents thought that the

assembly instructions were, in general, not presented in a good way. Respondents stated that the instructions were “insufficient, unclear, difficult to follow and that there was no connection between text and pictures”. In addition, the order of how the components were presented to the operators was also perceived as bad due to that they were e.g. not presented in a logical sequence, similar parts lay too close to one another. Here the cognitive processes in *Level 1* of the combined conceptual model could be supported by using consistent layout, highlighting differences between similar objects and showing realistic pictures. *Level 2* was supported by giving an overview of the gearbox was presented placed just above the assembly area to complement the assembly instructions (showing both the finished product and a description of complex steps). Realistic pictures was also used to stimulate mental models (signs). By introducing the suggested changes to the station and work instructions the assembly errors was reduced and operator satisfaction was increased.
The second case scenario comprised the introduction of a mobile instruction carrier, in an automative company (for more details see Tommy Fässberg and Nordin (2010)). Instead of presenting the instructions in a binder, operators part of a pilot study were given cell-phones that showed instructions in real time. A request from the operators were to see the next three models in order to prepere if it was a complex (or heavy) engine to assembly i.e predicting future state (Endsely, 1995). Here *Level 1* was supported by providing consistent layout and reducing the amount of information (*signals*). *Level 2* was supported in terms of providing triggers for attention by vibration (indicating that a part with a history of quality defects were to be assembled) and by allowing a preview function showing the next three upcoming productions (*signs* activating stored behaviour). Operators stated that the device felt natural to use but that information could be reduced further, however detailed information should be available if requested. The tool changed the behaviour of the respondents for instance the device could be used when operators were faced away from the product thereby reducing the choice complexity.

The usefulness of the combined conceptual model is exemplified in Table 1. In the cases cognitive processes are supported so that production complexity can be reduced.

Table 1. Usefulness and application of the combined conceptual model on two case scenarios.

Description	**Case scenario 1: New instructions**	**Case scenario 2: Mobile instruction carrier**
Supporting cognitive processes (*Level 1 and 2*)	Consistent layout, sequenced instructions, highlighting differences between similar objects, showing realistic pictures	Consistent layout, *reducing* the amount of information. Triggering attention by vibration and presenting three upcoming product variants
Managing production complexity	*Simplifying* instructions by activating appropriate behaviour by providing relevant and easy information	*Simplifying* and making instructions more accessible by activating appropriate behaviour and *reducing* choices

4.2. Practical application and future work

The goal of investigating cognitive processes is to better manage complexity by for instance *simplifying* information flow, thereby *reducing* production complexity (Wiendahl & Scholtissek, 1994). This was seen in the case scenarios were the cognitive processes were supported. Therefore when designing instructions or support tools the suggested *Level 1* and *2* provide one way to understand what behaviour should be active and also how they can be activated (by information *signals* or *signs*). The information could therefore be *simplified* so that it is possible to find (M. R. Endsley, 2000) and interpret the information (G. Bäckstrand et al., 2008). This could help ensure that the interaction between humans and technology, in a complex context, is succesfully managed as needed according to ElMaraghy et al. (2012). A better management of production complexity could decrease process errors, achieve high quality, achieve good working conditions, fast processes, quick change-overs and to decrease cost (Heilala & Voho, 2001; Papakostas et al., 2010; Schleich et al., 2007).

The focus of this paper is *intuitive* processes which was seen as the main part of final assembly work. Future studies involve further describing the processes in detail, including also cognitive limitations so that errors can be avoided (J. Rasmussen, 1983). Model boundaries should also be investigated and it should be further tested how in practise cognitive processes could be supported. Understanding and supporting also unfamiliar situations and problem solving (active and controlled i.e. *reason*) connected to the final assembly stations could also be investigated further. This could include for instance maintenance or logistical issues as well as other domains. Future work could also include specifying the importance of the cognitive processes suggested in the model and new processes could be added.

5. CONCLUSIONS

Cognitive processes in complex final assembly can be described as intuitive e.g. fast, intuitive and efforless. To answer how intuitive cognitive processes can be identified and characterized in a complex context, a conceptual model was suggested by combining Rasmussens model for SRK -based behavior, Kahnemans model of System 1 and 2 and Endsleys model of situational awareness. The combined conceptual model consists of two levels where the processes in *Level 1* were identified as: *Gathering information, forming characteristics, recognizing elements* in a situation and the processes for *Level 2* were identified as: *Comprehending a situation, understanding importance of objects* and *how they can be used to reach a goal by conforming elements and connecting them to tools*. The case scenarios exemplify the models usefulness were in the first scenario new instructions supporting cognitive processes resulted in an increase of product quality and operator satisfaction. In the second scenario operator behaviour could be changed by introducing a support tool which included simplified and more accessible instructions. By supporting cognitive processes and simplifying the information given to the operator, operator performance and satisfaction could be increased thereby also decreasing cycle time and cost. This can be seen as a first step of developing a model that can be used to support and manage cognitive processes in a complex production context.

ACKLOWLEDGEMENTS

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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