Activity Analysis of Expert and Novice Operators in a Semi-Automated Manufacturing Process

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ABSTRACT

Designing a human-machine interface for a manufacturing process requires a good knowledge of both the work domain and the operators' representation. Ecological Interface Design (EID) offers some interesting tools that can be of help in the design process. The literature on cognitive control also offers a good understanding of operators' cognitive resources. Analysing the activity of both expert and novice operators through these two frameworks may help us to better understand the differences between them. A three-step protocol was followed: 1. the elaboration of a means-end hierarchy, 2. the extraction of schemes *via* interviews, and 3. the evaluation of the behavioural manifestation of schemes. In the present case study, interviews revealed that both the novice and expert operators of a manufacturing process shared a representation of the global process. However, in contrast with the expert operators, the novice operators did not develop an operative scheme that related to the machine. The results will be used as a basis for the design of a human-machine interface that will aid them to do so.

Author Keywords

Task analysis; cognitive control; expertise; interface design; aeronautical factory.

ACM Classification Keywords

H.1.2 User/Machine Systems, H.5.2 User Interfaces

INTRODUCTION

In a work context, a dynamic situation refers to complex tasks in which there are changing parameters over time, as well as uncertainties [4]. The operator must then choose his actions according to his goals and his knowledge or representation of the current situation. He cannot know everything about the situation; nor can he completely master the situation [4].

This work focuses on an activity analysis of operators in such a situation. More specifically, the case study involves a frame stretching activity in an aeronautical factory. This analysis aims to make recommendations for the design of a human-machine device that could support operators during decision making and process control.

We will first briefly describe the two frameworks we used to describe the system and the operators' activities, i.e., Ecological Interface Design (EID) [3] and cognitive control [4]. We will then describe how we operationalized them with regard to the case study. Finally, our results will be presented and discussed.

DESIGNING A HUMAN-MACHINE DEVICE TO SUPPORT ACTIVITY IN A DYNAMIC SITUATION

Ecological Interface Design

Ecological Interface Design (EID) aims to design easy-to-use interfaces for both experts and novices. It considers that people's capability to use perceptive treatment is a strength that interfaces should rely on. To give people the right affordance, the interface should represent the system's whole complexity, but also trigger expert shortcuts [1].

Abstraction Hierarchy

A means-end hierarchy is a tool for representing the system's complexity as a whole. It links goals and the means to achieve them using a five-level hierarchy, comprising functional goals, abstract functions, general functions, physical process and physical forms [9].

Whereas traditional interfaces mainly focus on lower level, ecological interfaces also represent the higher levels and the connection between the details of the hierarchy [1].

Skill-Rules-Knowledge (SRK) taxonomy

The second most important element is to convey any expert shortcuts. Whereas a novice will sequentially inspect every piece of information, an expert may create rules that allow him to directly link what he perceives with what he has to do. In reality, three levels of behaviour can be identified

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through the SRK taxonomy; these range from the more symbolic to the less symbolic, i.e., from knowledge-based behaviour and rules-based behaviour to skills-based behaviour [6]. A proper interface should allow the user to work within each subsequent level, and thus, include any relevant symbols, signs and signals.

Cognitive Control

Definition

Whereas the former framework only considers what we identified on a symbolic/sub-symbolic dimension, cognitive control may include a second aspect: the origin of data. Indeed, the subjects can support their action with external or internal information. Cognitive control may be considered as the articulation of the two dimensions [4].

At any moment of his activity, in order to master the situation, the operator has to find a balance between the cognitive cost and an acceptable level of performance [2]. The cognitive compromise, headed by meta-knowledge, will allocate the proper resources *via* cognitive control to achieve the desired performance.

Schemes

The operator has access to resources that include helpful elements from the environment. He also has internal cognitive resources, including representation. Among these internal resources are schemes [7].

A scheme is an invariant organization of one's activity in a class of situations. It is made up of five elements: 1. rules for action; 2. information that people consider to be true or pertinent regarding their activity, i.e., operative invariants; 3. goals or expected results of the activity, i.e., anticipation; 4. elements to modulate the activity, i.e., inferences, and 5. tools, i.e., artefacts [8].

METHOD

In order to collect the different information needed to use both frameworks, we created a three-phase protocol.

The first phase allowed us to elaborate a means-end hierarchy, as described in the EID framework [1], through global observations, documentation analysis, and interviews with researchers in physics.

A second phase was aimed at picking up the explicit representations of the people working on this task [4]. Thus, we interviewed two expert and two novice operators, and an industrial technician.

As we were expecting to find behavioural evidence of these schemes, we added a third phase. This was aimed at evaluating whether the actions of the operators differed according to their mental representations. Thus, eight months later, we returned to observe the operators' activity over the course of a week and using a detailed grid. The data were recorded using a pad and ACTOGRAM software. We observed two pairs: two novices and two experts. The support for the novice pair had changed; at the time, one of them was a student. On the final day, we observed one operator who no longer worked on this task but was here when the programs were made. We have called him a "mid-expert".

RESULTS

Workshop and Task Descriptions

Workshop Description

The objective of the workshop under discussion is to bend straight aluminium frames. These frames are U or T shaped in section, and can measure up to 10 meters long. They will eventually form the skeleton for planes.

To achieve this goal, frames go through many transformations: they are bent and stretched twice and undergo two thermic treatments. These phases are automatized but controlled by different operators. To reach the exact required dimension, the frame is then manually calibrated, trimmed by an automaton and manually calibrated again. These manual phases are the longest and most troublesome according to the operators; they are also the most expensive.

Both the management and operators believe that an improvement in the automated stretching and bending process could limit the calibration tasks.

Stretching and Bending Task

In this task, two operators work together. A support operator only helps with the handling of the frames; it is the pilot's job to control the process and the machine. He checks the frame tracking sheet for the references and correct stretching program, and the clamps and tools. He also loads the program and can modify it, although the latter is forbidden. The operators are also supposed to check the dimensions of the frame after each stretching process.

Physical Process and Means-End Hierarchy

The objective of the operators engaged in the stretching and bending task is to achieve the exact dimension in terms of stretching, bending, planarity and straightness. Moreover, the frame has to meet some quality standard concerning the final material state. These elements constitute the first level of the means-end hierarchy (cf. figure 1, a).

We considered that the physical laws that determine the process represent the abstract function level. These laws actually determine the results of the stretching. We extracted five elements for this level in consultation with the researchers in physics (cf. figure 1, b). Indeed, after the stretching process, when the force deployed by the machine is discontinued, the frame shape will change according to five characteristics. The first one is the plastic limit, which determines the minimum strength required to make the frame reach a plastic phase. The second characteristic is Young's modulus, which depends on the alloy used and determines how fast the material returns to its initial position. This return phenomenon, which is called the spring back, is the third characteristic; it depends on a combination of both the elastic limit and Young's modulus. The fourth characteristic consists of the faults that can appear in the frame's alloy. Finally, there are edge constraints, i.e., the forces applied on the frame by the tools used during bending; in other words, the wedge and tracks that keep the frame's section shape.

To reach the plastic phase and anticipate the spring back, the operator has to stretch and bend the frame using the hydraulic arms of the machine. The operator can change the position of these arms and the speed at which it moves. The speed should not impair the result of the process, except if an internal defect exists. The operator can also change the clamp of hydraulic cylinders that hold the frame. In order to achieve the exact shape required, the frame is bent around a mould, the size and position of which may change. Finally, the operator can refrigerate the frame at any point in order to maintain the material's characteristics after tempering.

With regard to edge constraints, the operator has to insert a wedge and tracks. The sizes of these two tools are fixed, but the operator could take another reference at this point in order to improve the process. It is worth noting that a project aimed at measuring these sections revealed that the dimensions of each frame are different.

Task Analysis

Interviews: Schemes and Cognitive Control

We present the results obtained by interviewing two pilots (one expert and one novice) and the industrial technician. We classified the interviews according to the scheme model [8]. Each operative invariant was then classified in terms of the means-end hierarchy.

Both the novice and expert operators underwent a common initial training as coppersmiths; consequently, they shared the same operative invariant relating to the general process. However, they differed with regard to their operative invariants for the operative side of the stretching: only the expert operator knew how to modify the program and was aware that speed has no effect.

Both the novice and expert operators used the measurements as inferences to modify their actions. However, whereas the expert created rules, the novice needed the symbolic level, implying a most important cognitive cost according to cognitive control model [4]. For instance, when a frame is not bent enough, the expert operator can directly add a certain amount of stretching. However, the novice would be inclined to investigate the possible reasons for the shortfall, such as the speed of the process. He may then call for help.

Behavioural Evidence of Schemes and Cognitive Control

A total of 54 different actions were made during the week. The appearance of each observed action per participant, per session and within a fixed 120 seconds time slot was counted. Making the hypothesis that the number of actions (denoted Y) follows a Poisson distribution, several Generalized Linear Models (GLM) were computed. This allowed us to describe a relationship between a measure and one or more variables (also called predictors). Here, the predictors were the time (in secs) from the beginning of the activity, the level of operator experience (expert (e), novice (n), "mid-expert" (me) and student (s)), the frame rank (the rank of the frame during the session) and style (the frame reference), and the stretching (first vs. second). The models were selected according to the Bayesian Index Criterion (BIC) using a stepwise procedure.

The results showed that time had no effect. An operator effect was found for only five of the models: "Angle", "Change Speed", "Manual Command", "Look Away", and "Talk".

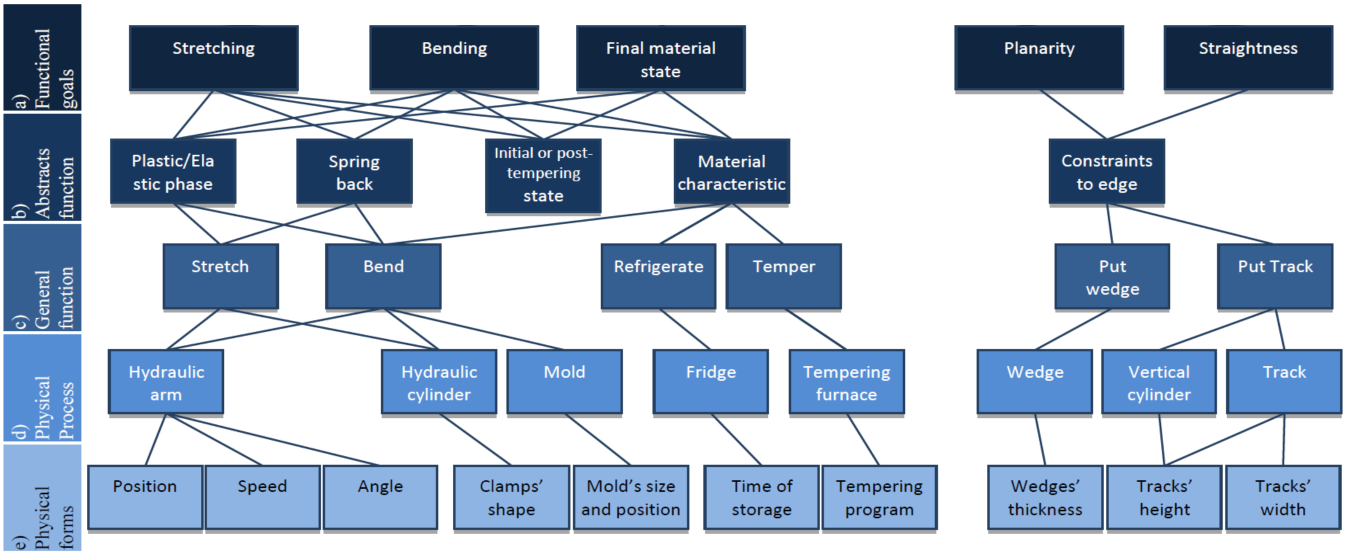

Figure 1: Means-end hierarchy for the stretching and bending task.

"Angle" means that the pilot checks the section's straightness. Measuring the angle acts as a control of the activity and a desire to improve the process. The best model for this action indicates an effect of the stretching process (first *vs.* second) and of the operator. According to the model, the expert operator is more likely to measure the angle (expected mean for the expert m_e= 0.26 action per time slot) than the other operators ($m_{me,n,s} \approx 0$), but only during the second stretching.

"Change speed" was coded each time the pilot turned the speed button. It is an element of the operators' scheme. The best model indicated an effect of the operator only. The expert used this button less (m_e=0.14) than the mid-expert, the student and the novice (m_{me}=0.93; m_n 0.73; m_s1.17).

"Manual command" was coded each time the pilot manually directed the machine's hydraulic arms. This happened during the second stretching to help the support operator. This action could indicate the reactive-anticipative dimension of the activity for more manual commands imply more trials. An effect of the stretching (first *vs.* second) and the operator was found. During the second phase, the expert used the manual command less often (me=0.57) than the other operators (m_{me}=1.71; m_n=1.32; m_s=1.83).

"Look away" was coded each time the pilot stopped focusing on the task to look around. The best model specifies an effect of the operator only. The expert (m_e=0.45) and the novice (m_n=0.42) looked away more than the others (m_{me}0.14; $m_n \approx 0$).

"Talk" was coded each time the pilot talked to the support operator or to anyone else. The operator was the only predictor. The expert talked more (m_e=1.44) than the others (m_{me}=0.36; m_n=0.39; m_s=0.06). Both "look away" and "talk" are indicators of the operators' distraction. Less distraction could indicate that more cognitive resources are allocated to the task, suggesting a more symbolic activity.

CONCLUSION

All the interviewed operators seemed to share invariants relating to the higher levels of the means-end hierarchy. However, in contrast with the novice and the industrial technicians, the expert operator developed an operative scheme that relates to the machine. To do so, he used the different levels of the means-end hierarchy. Thus, we were able to observe behaviours that reflect the expert operator's invariants. On the contrary, the three other operators did not control the result of their activity. They were not capable of modifying their activity to improve their outcomes; they had probably changed their acceptable performance.

According to EID [1], a good interface should link the lower levels of the means-end hierarchy to the higher levels. This is precisely what the expert does. In this case study, this would allow the novice operators to be aware of the possibilities for their actions on the machine and relate them to their existing knowledge of the physical process. We suggest that the consequences of each action on the lower level should be represented, taking physical laws into account. Moreover, the most important elements according to the expert operator, such as angles or bending should be emphasized. The interface would then afford the novice the appropriate corrective actions; he could change the tools' reference or, maybe, the program. Finally, the tools should be taken into consideration. This is in contrast with what is offered by the current simulation program. For the expert operator, it may reduce the number of iterations needed to achieve a good result and may also allow the operator a greater capacity for anticipation.

We are expecting to test such an interface in a subsequent phase of our work; indeed, a microworld [5] is developed. Furthermore, we are expecting to extend the qualitative results presented here by testing on a larger scale.

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