Who wants a cup of coffee?

Action Theory applied on cockpit design.

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In cockpit design the research has for a long time been dominated by cognitive psychology. Studies have been carried out that determine the difference in time for information recognition using different colours and different symbols in advanced displays. Results may show a significant time difference of some tenths of a second. Though the results can be of importance for specific displays, it is questionable if the results are significant, or even relevant, in the larger context. By applying a different perspective one can overcome deficiencies caused by this tunnel vision. It seems as though Activity Theory is currently the perspective that is most suitable for widening the analysis of cockpit work. Starting with basic principles of Activity Theory and its possible interpretations in commercial air traffic and user centred design, this paper aims to highlight the necessity of applying an Activity Theory perspective to cockpit design.

Basic principles of Activity Theory

Activity Theory recognises some basic principles to be central in analysis of human-computer centred work (Kaptelinin, 1996) such as;

Activity as unit of analysis

The first principle captures the large scope of Activity Theory and states that the smallest possible unit of analysis to understand how work is performed is the *activity*. The activity is defined in the relation to its desired outcome and is being driven by its own motives. People want to travel from point A to point B as fast as possible. The activity is thus flying the airplane. This effectively disables any narrowly defined behaviouristic-like studies such as those usually conducted by cognitive psychologists. It also implies that since activity is a product of history and culture these issues cannot be disregarded in the analysis.

Object-orientedness

The second principle states that while we as subjects interact with the world, the world is not of interest only because of our interaction with it. It is meaningful in itself because socio-cultural properties are as objective as physical properties. Humans don not act on physical items only because of their physical properties but very much care about other, more soft or implicit properties. Extending this principle to cockpit layout it might conclude that while cognitive psychologists may promote the use of a red warning light, the actual situation may show that the pilot sees it faster knowing that it is the fire warning light. Thus the meaning of the light may be as important as the colour.

Hierarchy

The third principle defines the hierarchy of Activity Theory. On the top floor we have activity as the least possible unit of analysis. The activity is constructed from actions, which are in turn carried out by operations. Starting the engines is a necessary action to be able to fly. The activity is constructed from several such actions, which in turn are built up from operations. In the case of starting the engines the operations could be reading the checklist, turning the right knobs, saying the right words over the radio. All these operations are only relevant in the view of the activity of flying the airplane. Expressing the different core interests with Activity Theory taxonomy Cognitive Engineering seems to be concentrating on *operations*, Distributed Cognition has recognised the value of observing *actions*, while none of those see to the large context, the *activity* of flying an airplane safely from point A to point B.

Internalisation-externalisation

The fourth principle deals with the way humans acquire and manifest their activities. Through interaction with other people we learn possible ways of conducting operations and *internalise* these into our minds. When we use these behavioural patterns to achieve a desired outcome we *externalise* the knowledge, so it may be observed and possibly corrected. Because these two concepts, *internalisation-externalisation*, can't be separated it is superfluous work to only try to map the way humans collect and store knowledge, as is done by classical psychologists. It is also meaningless only to observe behaviour from the outside without considering the mental processes lying behind the actions, as argued by proponents of Situated Action (Norman, 1993). Together though, these concepts can complement each other to form an understanding of how people think and what the physical consequences may be.

Mediation

The fifth basic principle of Activity Theory concerns the fact that manipulation of objects is mediated through artefacts or tools. These artefacts have been affected by culture through history, and the use of these artefacts has in turn affected the culture. Thus by studying the tools we can come to conclusions on how internal human processes work. When it comes to cockpit design it becomes somewhat complex since the designers of the tools are usually not the ones using them. However, it can be said that the aviation companies, who own the aircraft, have an interest in economics and because of the fact that educating pilots cost money the tools, i.e. the instruments in the cockpit, have had about the same design from the fifties up until the eighties. This approach has diminished the need to re-educate pilots since they have already been familiar with the tools. The pilots on the other hand have never really accepted the design, which has been manifested in such utterances as “This thing must have been designed by some Einstein!”

Development

The sixth principle states that to understand a phenomenon you also have to understand the development into the emerging form. Since every entity has a history it is not possible to completely grasp the wholeness of it by studying only its appearance per se, but also be prepared to inquire about the historical reasons. For example the phrase “firewall thrust” sometimes used by pilots refers to old times when the airplanes were equipped with a fire resistant wall between the pilot and the engine, which was then placed foremost in the plane. Firewall thrust became a saying to indicate that the throttles had been pushed all the way towards the wall, i.e. full throttle. Nowadays when the engines are placed under or behind the wings there does not exist such a firewall, but the expression is still used (Hutchins and Klausen, 1996).

Central issues in Activity Theory

In Activity Theory there are some central concepts that might have to be explained (Figure 1). These spring from the original model of Activity Theory by Vygotsky and have been complemented by Engeström (2000). First there is a *subject*, being the person that is central in the analysis at hand. In this particular case it is the pilot. The second core concept is the *object*. Problems can arise in defining what exactly is the object of a work activity (Engeström, 1990) but in this case it should be the airplane. It is the airplane that is central to the pilot's attention and not for example the airplane in relation to other airplanes, or the task of taking the airplane from point A to point B, however this might be described as the *objective*.

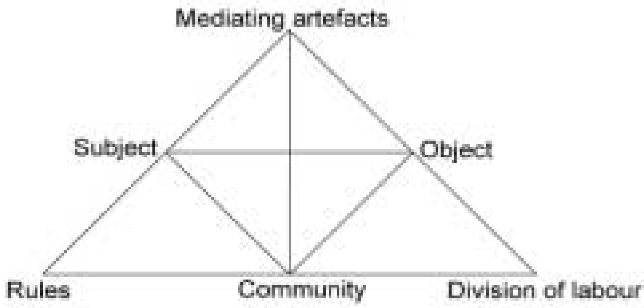

Figure 1: Triangular model of Activity Theory (Engeström, 2000)

That the airplane and not the safe travelling is the central issue for pilots may be confirmed from an old saying concerning airplane safety. When you cannot cope with the immense amount of information coming from different warning systems in the airplane during a critical period (i.e. some kind of malfunction) you should do things in the following order: *aviate, navigate, communicate* (e.g. Billings, 1997, p.66). With this interpretation the separation of airplanes would fall under the *navigate* headline.

To be able to control the airplane the pilot may use some *mediating artefacts*, or tools. These may not only be real hardware objects such as hydraulic servos or advanced displays. They may also be mental tools such as routines and procedures. Some of these may be existent the entire time of the flight although more or less conscious such as mechanical knowledge of the plane structure. Other artefacts may be taken into use only when explicitly needed such as engine levers or emergency routines.

It is also recognised that the flying is not an activity performed by the pilot alone. Depending on the type of airplane flying is a cooperative work between the pilot, the first officer and in some cases a second officer. The successful outcome of flying depends on the competence of these people, not by themselves but as a group (Hutchins and Klausen, 1996). Together they form a *community*, as Activity Theory researchers would say. The community is not a static entity but may be subject to change depending on the situation. During autonomous flight the community consists of the cockpit crew. Considering a situation where an air traffic controller identifies a possible collision between two airplanes and calls the two on the radio, the community now consists of the previously mentioned cockpit crew, the air traffic controller and the cockpit crew of the other airplane.

The cockpit crew have an agreed *division of labour*. Very often the different operations needed to perform a good job in the cockpit are not explicitly divided among the crew, but rather, since they all know what should be done in order to achieve a successful outcome the division is implicit and occur by the moment. Since they all know what should be done they can also check the right behaviour in the person currently performing the operation (Hutchins, 1990).

In carrying through the activity of flying the pilots must follow a set of *rules*, which incorporate issues of responsibility. These rules may be national and international laws concerning air traffic or explicit codes of the airline company but may also be implicit codes or standards of behaviour set by the community of pilots. An example of such implicit rules is the fact that redundant readbacks occur, not being a legal requirement but considered good practice in the aviation community. The issue of responsibility has been a dear subject in aviation automation literature. The captain of the airplane is ultimately responsible for the safety of the aircraft and its crew and passengers. That might seem reasonable enough, but with increased automation the issue becomes somewhat awkward. Should the pilot disregard an automated warning leading to an incident he will be held responsible. Still it seems reasonable. However, should the pilot trust an automated warning that turns out to be false he will still be held responsible. Considering that some 70% of ground proximity warnings are false (Billings, 1997) the absurd situation becomes clear. With the perspective of Activity Theory these kinds of issues surface during analysis of cockpit design, and not only during juristic debates, which is often the case today.

User centred design

The tradition when designing cockpits has been largely set by cognitive psychologists or engineers as mentioned earlier, leaving pilots very much out of the design procedure. Tests may have then been conducted that promote the use of some special design. In these settings test pilots were often used as test subjects. Knowing that test pilots were initially used for testing airplane structures it seems rather irrelevant to have them test instrument design supposed to be used on commercial pilots with totally different training and experience (Mårtensson, 1999).

In operating a ship, a related area, construction companies often incorporate a captain of a ship for designing the bridge. This is done for two reasons; firstly the captain represents the end user. This is seen as somewhat a guarantee for making the bridge a good work place from the mariners' point of view. Secondly, should someone claim that the final result (the bridge layout) is bad, the construction company can claim that this is what the user wants, a sort of non-liability guarantee.

The interesting here is the way the designing captain approaches the problem of "designing the bridge". He (most of the time it is a he) has the power to construct the best of interfaces, yet one of the first things to be mentioned is: the coffee table. Imagine standing on a ship's bridge. In front of you there are joysticks, levers, knobs and lots of advanced displays showing the information from hundreds of sensors around the ship. Now turn around. The advanced technology is behind you and in front of you there is a table, or some kind of shelf, with coffee, tea and cookies. This is something that the cognitive engineer might not have thought of. But is it of vital importance for the safety of travelling by boat that the captain and the other mariners get their coffee? Probably not, but one has to think of that the navigating of a ship is not only coping with lots of information during an intense period of thirty minutes, or even thirty seconds, as some cognitive engineers seem to think. It is also coping with the boredom of nothing happening for hours, during which you can write some reports or file some timetable documents.

While flying a commercial airplane is a physically more static activity than operating a ship the work is still not only the successful pushing of the right buttons, especially on longer flights. Flying an airplane from point A to point B is divided into three main sections: climb, during which the airplane acquires its cruise altitude, approach, in which the airplane descends for landing, and en-route being the actual flying in between. The most critical periods, both concerning stress on the plane structure and the pilots, are during climb and approach. The climb phase usually takes twenty to thirty minutes depending on cruise altitude, and the approach phase is about the same. This means that during shorter flights (e.g. Stockholm-Copenhagen, 75 minutes) the critical climb and approach phases constitute large parts of the flight. However, most flights occur on longer distances making large parts of the work tedious and eventless. During this time the pilots function as monitors in case something should go wrong. Some consequences of this are (Bainbridge, 1983) that the skills that are needed for managing the technology in eventful situations may be forgotten since the opportunities for practice are very few. In addition, when events actually occur they often come together triggered by each other because of tight coupling (Perrow, 1984), so that the situation often becomes unmanageable (Mårtensson, 1995)

Should pilots have more influence on the design of the cockpits, they would probably focus on different issues than engineers leading to different design. The connection between user centred design and Activity Theory is of course that pilots' point of view is focusing on the activity of flying an airplane.

Conclusion

The deficiencies mentioned above have been enabled largely because of the methodology used in research and development during the years. Aircraft development was initially performed by idealist engineers who wanted to fly, thus concentrating on hardware construction, often with a heuristic methodology. Later (cognitive) research was performed leading development away from the heuristics and more towards an analytic form. However, it was, and is still, conducted mainly by scientists from an experimental psychology tradition. Both of these facts indicate that history is a contributory factor to why aircraft automation behaves as it does today. This is also very much in line with the introduction given by Winograd & Flores (1987). They claim that analysis in the rationalistic tradition where the world ideally lets itself be explained by mathematical formulas is impossible since the world is more complex. From the cognitive engineering point of view previous history is not highlighted as an important factor, or even recognised as existent. Other points of view, such as Distributed Cognition (Hollan, Hutchins et al., 2000) and Activity Theory (Engeström, 2000), have however recognised the importance of culture and history. Although the main thesis in those works is that the *activity of interest*, i.e. flying, is subject to history it is also true that the effects of research, being the designed user interface, is affected by the history of research itself. Actually, the two entities are closely connected in a historical interaction in that they have affected each other. Thus the research is affected by the way cockpits look, and cockpit design is affected by the way research is conducted.

Activity Theory is presently the theoretical perspective in human-computer interaction that has the widest unit of analysis. Cognitive Engineering concentrates on providing information to the pilot in an effective and efficient way. This may be admirable but the way it has been done has been subject to a form of myopia. Research has been so concentrated on the specific details that the big picture has in some cases been lost. *It is all about flying.* In performing this kind of specific studies (i.e. concentrating on details) there is also a risk of forgetting other details that might be of interest. For example, in the transition from mechanical instruments to the use of cathode ray tubes the colouration has been subject to much research but the small differences in perspective because of two-dimensional representations being used instead of actual mechanical devices (being three-dimensional) has not. It is as if there exists a parallel to the ironies of automation in research: research is being done to subjects that easily let themselves be studied. Other subjects are left aside, either from oblivion or simply because of the law of least resistance. This is not to be seen as a major critique of current research but more of a silent statement.

The conclusion from this reasoning is that if we should let pilots into the realm of cockpit design it is very much likely that future cockpits might look somewhat different than today. This is based on the assumption that pilots have a larger scope of what is actually going on in the air, and the result might be that a good place for placing the coffee cup increases the overall work performance in an implicit way. Incorporating this larger view in the analysis is actually done using the elements of Activity Theory. So, when pilots know where to put their coffee cup the issue might be; who wants a cup of coffee?

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