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Man-Machine teaming: a problem of Agency

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Abstract: Automation technology is a ubiquitous phenomenon that is profoundly changing our everyday life. While the public is generally enthusiastic about the possibilities that it offers, recent tragedies remind us of the difficulties human operators have in cooperating with highly automated systems. This issue of cooperation amongst team (and/with automates) has led research on (team) performance and situation awareness investigating how computer might support collaboration between operators. However, after decades of research, the “cognitive coupling” between human and machine remains difficult to achieve. In this paper, we outline that the recent explosion of interest in the experience of being an agent (“agency”) opens interesting novel avenues to explain and compensate such difficulties. The sense of agency refers to the feeling of control over actions and their consequences. In the first part of this paper, we present some works indicating that automation technology can alter the agentic experience dramatically. Then, we discuss why such change in agency can dramatically impact operator performance and system acceptability. In the last part of this article, we propose to apply the framework of agency to the HMI domain and to take into account how the information provided by an automated system influences how an operator understand and control such system. Taken together, the different studies presented suggest that the science of agency provides us new conceptual tools and measures to analyze agent-system interaction. By using these tools, engineers could design more acceptable and more controllable automated interfaces and optimize human-automation cooperation.

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During the past 50 years, automation has dramatically changed our modern society. At work, at home, in the street, automation technology has permeated all the aspects of our lives. We also use technology for communication, education, banking, purchasing and so on. Still more changes are anticipated in the future with the explosion in artificial intelligence. How such developments will shape the future is not entirely clear, but the inexorable drive toward even more automation will continue. Crucially, whatever the advantages of using any particular automation technology, it is clear that it has profoundly changed human activity. Understanding the characteristics of this transformation is vital for successful design of new automated systems.

1. MODERN SOCIETY AND AUTOMATION TECHNOLOGY

Automation refers to the process of entirely or partially allocating the activities constituting a task usually performed by a human, to a machine or a system. Nowadays, people are accustomed to interact with automation technology. But why use automation? What is the thrust behind system automation?

The initial rationale of introducing automation is to reduce operators' workload, reduce operational costs and errors, while increasing precision (Sarter, Woods, & Billings, 1997).

It is clear today that without automation, safety-critical industries could not achieve the current levels of safety. Between 2012 and 2016, the aeronautics industry achieved a rate between 2.1 and 3.1 fatalities per million departures (International Civil Aviation Organization, 2017), partly thanks to multiple systems offering vital automated aids. For example, the introduction of the Ground Proximity Warning System (triggers an alarm if the aircraft is too close to the ground) answered the necessity to stop “controlled flight into terrain” (functioning airplane under the control of the crew is flown into terrain with no awareness of the crew). Up until 1955, U.S.A. had a rate of 3.5 controlled flights into terrain per year. Since its introduction in 1974, there has not been any case in the U.S. airspace (Sabatini, 2006).

In same time, automation technology comes with enormous savings. In aviation domain, automation technology has for example allowed for reduced fuel consumption with the implementation of more fuel-efficient climb and descent patterns or more efficient lateral navigation. Automation also allows operation in inclement weather and may cut maintenance costs by more effective use of the equipment.

It is now clear that automation technology leads to superior productivity and operativeness. It presents a huge potential to extend human performance and improve safety. It is also clear that the complexity and cleverness characterizing many such systems have tended to focus public attention on the

technical capabilities of automation. However, the interposition of automated systems between human operators and processes has dramatically changed the nature of human activity, often in ways unintended and unanticipated by the designers of automation. As a matter of fact, the role of the human actors tends to evolve from direct control to supervision. This change is far from trivial and creates new burdens and complexities for the individuals and teams of practitioners responsible for operating, troubleshooting and managing high-consequence systems.

2. AUTOMATION, OUT-OF-THE-LOOP AND COOPERATION ISSUE

System automation has been classically considered as a simple substitution of a machine activity for human activity, named “substitution myth”. Unfortunately, such assumption corresponds to a distorted reflection of the real impact of automation: automation technology transforms human work and forces people to adapt their skills and routines (Dekker & Woods, 2002). This transformation has many negative performance and safety consequences, a phenomenon called the Out-Of-The-Loop (OOTL) performance problem (Endsley and Kiris, 1995).

2.1 The Out-Of-The-Loop performance problem

Empirical data suggest that traditional automation could dramatically impact human performance in case of system failure. Among these difficulties, we can cite a longer latency to determine what has failed, to decide if an intervention is necessary and to find the adequate course of action. Several accidents (for example the Three Miles Island nuclear incident or the Flight Rio-Paris 447 crash) illustrate how supervisors seemed effectively helpless when attempting to diagnose the situation, determine the appropriate solution and retake control when the automatic equipment fails. Because automation is not powerful enough to handle all abnormalities, this difficulty in “takeover” is a central problem in automation design.

Cognitive engineering literature has discussed at length the origins of this OOTL phenomenon: decrements in vigilance such as reduced sensitivity to important signals, complacent or excessive trust in system ability, and loss of operator situation awareness have been pointed as potential contributor to this phenomenon. In consequences, different solutions have been proposed by the human factors society. Some of them consist to train human operator to produce efficient behavior in case of system failure. Other solutions propose to manipulate the level of system automation, sharing the authority between the automation and the human operator (for example MABA-MABA methods, adaptive function allocation) to increase both vigilance and SA. If these traditional approaches have the virtue to partially decrease the negative consequences of automation technology, the OOTL phenomenon remains a challenge for human factors community after decades of research.

Recently, more holistic approaches have been proposed to encompass the difficulties coming from the introduction of automated systems (Hoc, Young, & Blosseville, 2009; Banks, Stanton, & Harvey, 2013). As a starting point, the

following assessment: in most of cases, errors occurred in case of misunderstanding between the human operators and the machines, especially with strongly automatized environment. With this in mind, this framework has introduced a new vision of the OOTL phenomenon, from human error to interaction failure.

2.2 OOTL and the human-machine interaction failure

Creating partially autonomous machine agents is, in part, like adding a new team member. One aftermath is the introduction of new coordination demands and the emergence of new classes of issues due to failures in the human-machine relationship. In this sense, the main problem with automation is not the automation itself, nor the human operator itself, but rather how to design an efficient human-automation interaction (Norman, 1990).

This issue of cooperation amongst team (and/with automates) has led research on (team) performance and situation awareness investigating how computer might support collaboration between operators. This line of research has provided interesting concepts and methods: shared SA (Endsley, 1995; Salas et al. 1995), distributed cognition framework (Hutchins, 1995; Stanton, 2016) or adaptive automation (Miller & Parasuraman, 2007). These frameworks highlight the importance of the information processing and the communication between human operators and automated systems. These works have brought different human factors/ergonomics (HF/E) principles as a solution for better team play. For instance, it has been proposed to design automation systems as chatty co-drivers providing continuous relevant feedback to the driver to improve human automation interaction (Eriksson & Stanton, 2015; Stanton, Dunoyer, & Leatherland, 2011). In the same vein, Dekker and Woods (2002) proposed several principles to shape how information about automation and the processes in controls are displayed to the operator to enhance human-automation teaming: highlighting changes, displaying future projections, and visually integrating information. Such approach follows Norman’s (1990) recommendations about the “*need to provide feedback about the state of the system in a normal, natural way, much in the same way that human participants in a joint problem-solving activity will discuss the issues among themselves*” (see also Christoffersen & Woods, 2000; Dekker & Woods, 2002; Klein et al., 2004).

Our work aims to progress in this way. In this sense, we propose a complementary approach based on the recent explosion of interest in the experience of being an agent (“agency”). In the rest of this paper, we outline how this new framework opens interesting novel avenues to explain and compensate the difficulties associated to the human machine cooperation.

3. AUTOMATION TECHNOLOGY AND SENSE OF AGENCY

The term ‘sense of agency’, or sense of control, is the subjective awareness of initiating, executing, and controlling one’s own volitional actions in the world (Jeannerod, 2003). It refers to the experience of controlling one’s own actions, and, through them, events in the outside world (Chambon &

Haggard, 2012). This form of self-awareness is important not only for motor control but also for social interactions, the ascription of causal responsibility and serves as a key motivational force for human behaviour. Unfortunately, the progress in automation technology can alter the development of this sense of agency.

3.1 Automation technology and the loss of agency

Recently, the concept of agency has been applied to the HCI domain (McEneaney, 2013; Berberian et al., 2012; 2013; Obhi & Hall, 2011; Limerick, Coyle & Moore, 2014). During the interactions with technology, it has been shown that the simple process of producing an action to cause an intended outcome is dependent upon several variables that can alter the agentic experience dramatically. In particular, automated systems can generate interesting ambiguities of agency: who is in control, the operator or the system?

We have recently investigated the participants' sense of agency when performing an aircraft supervision task using a flight simulator under different levels of automation (Berberian et al., 2012). The task required the participant to observe a flight plan and after a random time interval, a conflict occurred due to the presence of another plane. The participant was required to decide an appropriate command and implement it using a button-based interface. In accordance with an established classification (Sheridan & Verplank, 1978), there were varying levels of automation of the task, from the user having complete control (no automation) to the computer executing the entire task with the participant simply observing (full automation). We found a decrease in agency (for both implicit and explicit measures) concomitant with the increase in automation (see Figure 1). We argued that the increasing level of automation tends to distract operators from action outcomes, decrease their sense of control and therefore disrupt their overall performance.

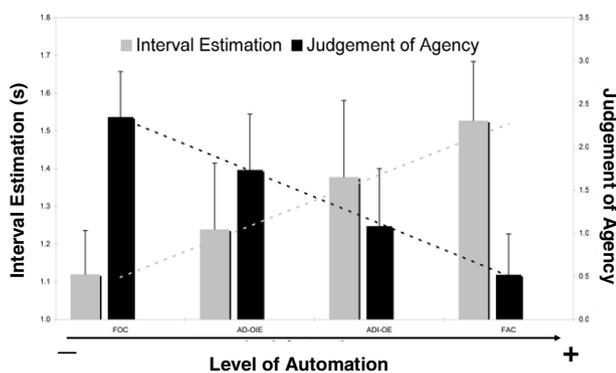


Figure 1. Modulation of interval estimates and explicit judgement of agency by automation level. From Berberian et al., 2012.

In same time, several studies related to agency in dyads tend to highlight a clear distinction between the sense of agency felt by an agent when he is interacting with another human versus with a machine (Glasauer et al., 2010; Poonian & Cunnington, 2013; Sahai et al., 2017a; Wohlschläger et al., 2003). As illustration, we have recently investigated the development of agency when engaged in a joint action with an artificial agent (Sahai, et al., 2017b). We have used the

Simon social effect (Sebanz et al. (2003). The standard Simon effect refers to the interference effect occurring when an individual has to respond with the right or left hand to a stimulus presented in an incongruent mapping location compared to a congruent mapping location. A conflict occurs because two actions representations (i.e., the correct action to perform and the spatially-induced automatic activated action) are activated and the participant has to solve the conflict in order to select the accurate behavior. Interestingly, using a joint Simon task, Sebanz et al. (2003) have found evidence of a social Simon effect, suggesting that during joint actions, actions of others are represented in our own motor plan (Sebanz et al., 2003). In our study, we added an implicit measure of agency (the intentional binding effect, for more details see Haggard, Clark & Kalogeras, 2002) to the Simon task in order to study the evolution of the sense of agency during human-human joint action but also during human automation joint action. First, our results indicate that both social Simon effect and the sense of agency are developed in case of joint action with human. In contrast, both motor interference and sense of agency disappear when engaging in human-machine interaction. Taking together, these results indicate that sense of agency appears difficult to develop when engaged in human machine interaction. Before going further on what we can learn from such difficulties, we aim to show how this decrease in sense of agency could dramatically impact human operator.

3.2 Loosing your agency: not a detail

What makes our understanding of agency especially relevant is the fact that a decrease in agency could generate critical concern regarding both automation acceptability and operator behavior. As pointed by Baron (1988), “*the major human factors concern of pilots in regard to introduction of automation is that, in some circumstances, operations with such aids may leave the critical question, who is in control now, the human or the machine?*”. This ambiguity about who is in control could impact user acceptance. Although performance and acceptance are often positively correlated, high levels of performance do not guarantee user acceptance. As pointed out by Shneiderman and Plaisant (2004), users strongly desire the sense that they are in charge of the system and that the system responds to their actions. In that sense, a decrease in the sense of control when dealing with highly automated systems has the potential to seriously threaten the system's acceptability.

In addition, the loss of agency could also impact human performance. Particularly, studies investigating error-related potentials (i.e., cerebral activity associated to the monitoring of the consequences of an action, e.g., San Martín, 2012, for a review) show a degradation of monitoring associated with a reduction in the sense of agency (Li et al., 2011; Kühn et al., 2011; Bednark & Franz, 2014; Timm et al., 2014; Caspar et al., 2016). In addition, relation between sense of control and one's motivation and willingness to make efforts has been recently proposed. For example, Eitam et al. (2013) demonstrated that task motivation is increased when control over an effect can be clearly established by the participant. In that sense, decrease in the sense of control could directly

impact the performance of human operators in system supervision associated with a “diffusion of responsibility” (Caspar et al, 2017).

The loss of agency has been also proved to disturb the attribution of responsibility. The sense of agency is known to underpin this concept of responsibility (Haggard, 2017) and the feeling of being an agent seems intimately linked to the experience and allocation of responsibility (Moretto et al., 2011; Frith, 2014). This loss of agency might therefore constitute a form of moral disengagement regarding our actions and disturb the mechanism classically used to regulate human behavior (Bandura, 1999). As illustration, Caspar and colleagues (2016, 2017) show that the decrease in the sense of agency leads to an increase in antisocial behavior indicating that people’s choice to act ethically or not, that is, to carry out actions that are judged to be “right” or “wrong” is shaped by our own beliefs about our involvement in the results of the action.

A major challenge in the HCI community with the next generations of highly automated systems is precisely to determine how to compensate this decrease in the sense of control and acceptability. A better understanding of the role played by the sense of agency may therefore provide a useful framework for thinking about interactions with automated technology and particularly to optimize human-automation interaction.

4. AGENCY AS A GUIDELINE

Several recent laboratory studies have improved our understanding of this fundamental mechanism that has been explored in various domains like in psychology (Aarts, Custers & Wegner, 2005), psychopathology (Farrer et al., 2003) and neuroscience (Tsakiris & Haggard, 2005). Interestingly, these studies have shown that a variety of sources of information (e.g., one’s own thoughts, interoceptive sensations, external feedback, etc.) are involved in the authorship processing (see Moore & Fletcher, 2012).

Although, the mental processes contributing to the sense of agency are not fully understood at this time, predictability appears as a main component of the development of this experience of agency. Indeed, the different approaches propose that we derive a sense of being the agent for our own actions by a cognitive mechanism that computes the discrepancies between the predicted consequences of our own actions’ actual consequences of these actions, similarly to action control models (see Blakemore, Wolpert, & Frith, 2002; Wegner, 2002). Interestingly, Pacherie (2012) argued that the different mechanisms underlying sense of agency for individual actions are the same kind of those underlying sense of agency one experiences when engaged in joint action. That is, the sense of agency in joint action is based on the same principle of congruence between predicted and actual outcomes.

However, with the progress of technology, current man-made complex systems tend to develop cascades and runaway chains of automatic reactions that decrease, or even eliminate predictability and cause outsized and unpredicted events (Taleb, 2012). This is what we will call system opacity: the difficulty for human operator to see the arrow from system

intention to actual state and to predict the sequence of events that will occur. The lack of system predictability could generate difficulties for human agent to be efficiently involved in man-machine joint action. This intuition is supported by our results about our previous results in the Simon social task, the absence of motor interference observed on the incongruent trials indicating that participants were not able to represent the computer-generated actions into their cognitive system.

To overcome this opacity, interactions designers could use the tools and measures, provided by the framework of agency (and by extension, the one of joint agency). The science of agency may therefore provide a useful framework for thinking about interactions with automated technology. Notable, the three principles of agency proposed by Wegner and Wheatley’s (1999) could be relevant to improve human-machine interfaces. These authors claimed that an action is perceived as willed 1) when the thought precedes the action at a proper interval (called the priority principle), 2) when the thought is compatible with the reaction (consistency principle) and 3) when the thought is the only apparent cause of the action (exclusivity principle). Following that theoretical proposition, Wegner, Sparrow and Winerman (2004) have reported that priming effects (i.e., providing predictive information of what will happen next) is a good way to influence or to simulate prior thoughts and create a sense of agency even in the absence of any movement (see also Moore, Wegner & Haggard, 2009; Sato, 2009). In their study, participants watched themselves in a mirror while another person behind them, hidden from their view, moved her/his hands forward on each side where participants’ hands would normally appear and performed a series of movements. When participants could hear instructions previewing the movements, they experienced a higher degree of agency for these movements. This priming effect could then be used to improve communication between automation systems and operators to increase the feeling of control in a supervision context.

We have recently explored the relevance of the principles proposed by Wegner and colleagues in human machine interaction domain (Le Goff et al., 2018). Particularly, we explored the benefit of prime messages regarding system intention while supervising an automated system. In a series of two experiments, we tested whether providing information about what the system is about to do next leads to an increase in the level of user acceptability, concomitant with an increase in control and performance. Our results (see Figure 2) indicate that providing additional direction information about the system’s intentions impacts (1) system acceptability and (2) operator performance in case of system failure together with a change in allocation of attentional resources. Thus, our results suggest that displaying the system’s intentions prior to an action is a good candidate for maximizing both takeover efficiency and human machine teaming. Moreover, we show how the content and the timing of the information transfer to the human operator could maintain operator sense of control while promoting overall system performance. Indeed, our results indicate that the delay between prime messages providing system’s intentions and the system’s actions had a similar impact on both sense of

control and system acceptability whereas this impact differs qualitatively regarding the performance (i.e., quadratic versus linear trend), as suggested by the priority principle proposed by Wegner. In the same vein, we showed how we can use Wegner's congruency principle to design human-machine interfaces capable to compensate the negative effects of latency on action control (Berberian, et al., 2013).

Taken together, our results indicate that the principles proposed by this framework could help designers determine the parameters of the information (quantity, content, modality, timing, etc.) that should be primed by the automation to maintain a high level of sense of control in supervisory task and, as well, increase system acceptability.

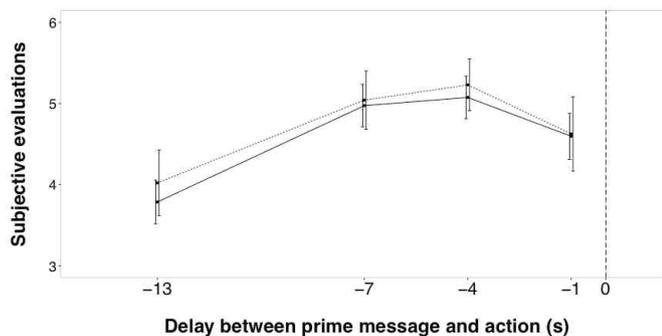


Figure 2. Mean values for the sense of control (dashed line) and the user acceptability (solid line) at each of the 4 delays. Errors bars are 95% CIs. From Le Goff et al., 2018)

5. CONCLUSION

We have seen through this paper that, despite all the benefits of automation, there are still issues to be corrected. We argued that these difficulties are mainly caused by human-machine interaction failure. In this context, we propose to use tools and methods offered by science of agency to understand how automation influences the humans who work with it and how humans feel about action control. We show how agency could help to characterize the OOTL performance problem and to propose interaction principles. We assume that the theoretical framework proposed should help design, specification and evaluation of future HMI to improve human-machine teaming by keeping the operator clearly, unambiguously and safely within the control loop.

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