The Problem with Automation is not Over-Automation but Lack of Automation Policy

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ABSTRACT
Although automation has been introduced in all areas of public life, what seems to be missing is a reflection at the organizational or societal level about a policy of automation. By this we intend appropriate declarations made at the level of rationale, future plans and strategies to achieve intended goals and most importantly how those achievements will impact on various aspects of societal life, from legal responsibilities to moral and socio economic issues. In some public spheres these issues are becoming quite controversial because automation opens up possibilities of profound structural re-organization; however, we lack a discussion across and within different work domains to help us review methods or even methodological principles needed to gather and organize knowledge towards the construction of automation policies. This paper uses a service organization from the Air Traffic Management Domain, NATS, as a case study to illustrate an example of an organization currently undertaking critical self-reflection about automation policy or lack of such, along with the illustration of some unresolved deep concerns raised by the development, introduction, and continued use of automation.

CATEGORIES AND SUBJECT DESCRIPTORS
J.2 [Physical Sciences and Engineering]: Aerospace.

GENERAL TERMS
Performance, Experimentation.

Author Keywords
Automation; Problematic Automation; Automation Policy; Organizational Resilience

INTRODUCTION
Although automation has been introduced in all areas of public life, from production to tertiary sectors, what seems to be missing is a reflection at the organizational or societal level about a policy of automation. By this we intend a declaration of rationale, future plans and strategies to achieve intended goals expressed not longer at a single mission level such as gate-to-gate trajectory management, but how those achievements will impact on various aspects of societal life, from legal responsibilities to moral and socio economic issues. While in some public spheres these issues are becoming quite controversial because automation opens up possibilities of profound structural re-organization, we lack a discussion across and within different work domains that help us to review methods or even methodological principles needed to gather and organize knowledge to the construction of such policy. For example, current concerns about the deep changes to be introduced in the British Public Health sector would likely benefit from a more open discussion about the relationship between automation and higher level societal goals (see Rozzi et al., 2010).

This paper uses NATS as a case study to illustrate an example of an organization currently undertaking critical self-reflection about automation policy or lack of such along with the illustration of some unresolved deep concerns raised by the development, introduction, and continued use of automation. Before discussing NATS-specific concerns we shall briefly review major issues within the cognitive ergonomic literature about the relationship between automated processes and human control.

MAJOR PITFALLS OF THE AUTOMATION PROCESS
Information and computer technologies provide an increasing number of opportunities to develop new solutions to assist operators/professionals across many domains of practice in managing complex socio-technical systems. There are, however, a number of concerns highlighting complexities and paradoxes embedded in the automation process. Bainbridge (1986) discussed the unexpected consequences of technology-driven automation which often relies on human reliability to be safely
operated. One of the “ironies” is that automated systems are often introduced on the ground that humans are less reliable than automation because of “intrinsic” limitations in their ability to monitor for unexpected, unsafe events in a stream of a routine flow of events. Paradoxes linked to the introduction of expert systems have been extensively emphasized (Billings, 1991; Norman, 1988; Woods, Cooks & Billings, 1995, Sarter & Wood, 1997). Inappropriate design choices might result in an increase of operators’ workload, in an excessive demand on working memory, in a difficulty to co-operate with team members, and finally it might slow down the development of expertise (Sarter & Wood, 1997). Automation is expected to assist operators in achieving the overall system goals in a more cost-effective way. These expectations have, at times, relied on a number of mis-beliefs (Mosier, 1996). In fact, although it might lead to “de-skilling”, automation does not decrease the requirements for expertise. Some have nevertheless been led to believe that expert systems can replace the need for or even decrease the standard of expert operators. This claim does not consider that automation has to be constantly adapted to its operational context to be effective (Vicente, 1999). This is because expert systems have a limited scope with respect to the variety of objectives characterizing activities in complex socio-technical systems. This variety reflects the ability of expert operators to identify ways to improve the system performance in routine situations. The role of operators when interacting with complex technical system has often been emphasized in relation to their ability to manage exceptions. While this is true, it should not be neglected the finding that operators systematically go beyond the prescribed practices to enhance system’s efficiency (Wright & McCarthy, 2003). An old study involving observations of maintenance operators, reported that almost one third of the times operators have been observed making an informal use of available tools (Leport, 1970). By informal it is meant that the tool is not used for the purposes it was designed but rather with the intent of making the corrective action more effective. This phenomenon has already been well documented and studied within the francophone ergonomic tradition quite long ago (Cuny, 1979, De Keyser, 1991, Leport, 1970). The informal use of tools and procedures reflect often a search for an improved efficiency, not just a solution to unexpected problems. Similarly, the spontaneous generation of linguistic code has been observed in different operational settings (Cuny, 1979). Notice that deviations from standard communication patterns have generated fatal misunderstandings such as in the case of air traffic controller / aircraft pilot radio communications (Mell, 1993, 1994). In spite of these fatal accidents, deviations from standard use are often generated with the aim of achieving task goals. In this respect, automation should support operators in finding the best way to achieve the goals while limiting the negative consequences of possible misfits between tools adaptations and task constraints and goals (Vicente, 1999). As part of the integration process operators will engage in «finishing the design» of the tool with respect to its original intended use (Rasmussen, 1986), i.e., improving the fitness between the tool and the complexities of the operational environment.

**AUTOMATION AND INFORMATION PROCESSING STAGES**

In an attempt to characterize automation with respect to models of information processing, Parasuraman, Sheridan & Wickens, (2000) have used a simplified model of human decision making and problem solving. The model allows the classifying of technological innovations according to four stages:

- (i) information acquisition ;
- (ii) information analyses ;
- (iii) decision selection;
- (iv) action implementation.

The introduction of new technology might interact with cognitive processing in each of these stages with differing degrees of automation. The allocation of tasks to humans and machines depends then on the level of automation chosen. While the classification schema does offer a means to group technological innovations across different domains, guidelines for function allocation do not seem straightforward. Criteria for deciding how to do task sharing have to be based on an understanding of the impact of automation on the targeted communities of practitioners. Neglecting, for example, the crucial role of cooperation or adaptation processes like "finishing the design" does not seem a very promising start for deciding on task allocation. Further, such a simplified model of human cognition and of human-computer interaction might mislead designers and engineers to believe that a fairly simple algorithm can generate the desired answer to a very complex and still unsettled issue (see also Dekker and Woods, 2002). Some examples discussed below will illustrate the pitfalls of such naïve assumption.

For example, automation concerning the (i) acquisition and (ii) information analysis stages involves the organization of incoming sensory data. A stated purpose is to decrease attentional demands of operators by highlighting or cueing relevant information while leaving the rest un-cued but still accessible. Yet, this apparently simple solution neglects considering a number of issues. The assumption here is that human information processing capacity is limited and thus the number of items that can be processes at anytime cannot exceed that capacity. While this is not wrong, this statement neglects considering that there is no an obvious way of "measuring" that capacity as it is subject to people’s expertise, organization of labor and the development of new
working practices. In addition filtering “relevant” information raises the issue of “context sensitivity” (Woods, Patterson, & Roth, 2002). What needs to be noticeable depends on the situation which includes other related data, the “history” of the process, the intentions and expectations of the observers (Mumaw, Roth, Vicente, & Burns, 2000).

A higher level of automation within the information analysis stage implies the temporarily or permanently hiding of certain information. For example in Air Traffic Control (ATC), certain electronic displays of future traffic problems “hide” or “reveal” information according to the role of operator within the team. Or, the available data might be automatically organized in terms of problems to be dealt with in a given priority order. Notice that information filtering, problem formulation and priority assignment, all involve anticipating how the system under control is going to evolve. Automation of some anticipatory functions is then involved in the design of predictor displays introduced in both the flight deck and ATC to assist operators to project future courses of flight.

Automation interacting with the third stage of decision making leads to the selection of a course or several courses of actions. Automation here might assist operators in calculating the best option(s) given the constraints of the current situation. For example the Flight Management System (FMS) in the cockpit can, more effectively than pilots, calculate the most cost-effective trajectory in terms of gas consumption and timing.

In ATC, decision aids assist controllers by offering solutions to traffic problems and in this respect several systems have been proposed and evaluated (e.g., ERATO, HIPS, URET, IFACTS) (Mendoza, 1999). At this level of automation a range of alternatives are proposed, leaving operators responsible for making the final choice. A more advanced automation would give very little or no choice to operators as to what solution to implement. This implies automating the process of evaluating costs and benefits associated with each alternative. The problem is that the criteria used in the automated evaluation process are not likely to include all of the factors affecting human decision-making. In fact there will always be a number of conditions where the proposed solution would need to be adjusted to reflect local contingencies. Therefore it seems crucial that a high degree of automation at this stage of decision-making, leaves open the possibility of deciding whether or not to implement the course of actions. For example a number of studies on Traffic Collision and Avoidance System (TCAS), have shown that pilots do not always comply with the advice provided by the automation (Amaldi et al., submitted; Garfield, & Baldwin, 2004) unless they can verify its compatibility with external conditions. Notice that improving an understanding of the criteria underlying the solution proposed facilitates a complying behavior (Lee & Lees, 2007; Pritchett, & Hansman 1997).

Automation intervenes in the last stage of decision making through the implementation of the course of actions. For example digital data link will allow air traffic controllers to automatically uplink a pre-edited clearance into the plane’s FMS. Notice that the clearance could be a computer-selected option to an automatically identified traffic problems. Current proposals to uplink ACAS to FMS are another example.

WHAT IS AUTOMATION FOR?
What is then automation? It is a transformation of a world state accomplished by an electro mechanical device with or without human intervention. Our previous discussion aims at classifying the level of the involvement with humans with respect to cognitive operations involved in decision making.

What is automation for then? It is the means by which we extend our cognitive skills; by which we aim at increasing the resilience of the operational system (by introducing for example, back up sub-components); by which we aim at increasing productivity by enabling the system with new tools that increase the throughput.

What can be automated? There have been cases, in the history of R&D in Air Traffic Management when (over) ambitious automation projects have been withdrawn. Lack of mature technology or too many contingencies that made it impossible to proceduralise operational practices. One apparent rational was that whatever could be made faster and more reliable through the use of automated device, it should.

For a few decades, ATM operations have been the object of R&D efforts to make them faster and more reliable through the introduction of automation. There was a lack of consideration of the wider impact of those innovations. For example, increasing traffic throughput en route was not connected with the need to increase airport capacity. Increasing airport capacity, however, has been the target of serious environmental concerns.

Starting on the assumption that the complexities of current system require automated aids, the coupling of computers to air traffic management has surely resulted in an increase of safety and productivity. Nowadays targeting individual human limitations with respect to system control is not longer a viable strategy for expanding current business. The main challenge seems to have shifted from designing interfaces usable or trustable (although these are still serious concerns) to mapping out the added complexities and the profound consequences of the technological innovation process. For example, recent debates by environmentalists have challenged that Civilian Air Traffic is an important contributor to CO2. To what extent, then any technical innovation could be planned to address the pollution of the atmosphere? The main point to be raised is that the human-computer interaction unit of analysis has to be embedded in a larger context to target limitations and
contradictions of the entire system, rather than marginalizing the human as the ‘limiting factors’ to system development.

**NATS AUTOMATION PROBLEM STATEMENTS**

NATS is currently reviewing their position and their implicit assumptions with respect to automation. At this stage NATS is seeking views in the face of unexpected side effects linked to increasing complexities from all parties involved in the design, implementation and use of the existing or planned automated systems. Such process of critical self-reflection aims at enhancing its resilience in the face of increasing complexities linked to ongoing technological innovation. The notion of organizational resilience has become popular in the area of organizational risk management (Hollnagel, Woods, et al. 2010). The more an organization builds its own resilience, the more is capable of adaptively responding to hazardous events. We extend the notion to situations where the planning of profound changes cannot indeed include all of its major contingencies. Given the increased complexity introduced by more and more powerful technology, NATS attempts to move from a rather patchwork to a more holistic approach seems worth reporting. In the following we illustrate NATS recent problem statements with the aim to receive feedback from interested parties, i.e., management, front line operators, industries, academics and possibly experts in ethical/legal issues.

**Problem statements**

At the moment NATS has compiled 14 statements which we grouped into 7 groups.

Group Statement 1. Lack of definition/vision: There is not an agreed set of definitions about the scope of automation, i.e., to what extent is mostly technology- or problem-driven. This results in confusion and lack of clarity in planning and communication. Different people have different expectations and different requirements regarding what automation will deliver. Similarly there is not a single agreed vision for automation. The scope of automation needs to be defined and agreed. The vision for automation needs to be clarified and made explicit. This vision needs to drive decision making. Automation affects every aspect of the business – it determines how people are selected and trained; how many people remain in the system and NATS’ capacity to generate income. There is no clear definition of the future levels of automation that we should be planning for and expecting.

Group Statement 2. Responsibility and role allocation. No single clear picture of how automation will affect MOPS\(^1\) – in particular the responsibility of the operational staff for the decision making process. The literature previously reviewed suggests how automation can interact with the problem solving and decision making process. These options might help establish a common platform to discuss options. The introduction of new automated technology will affect the role of the human. It is vital that human strengths and vulnerabilities are accounted for in the design of roles. Also, it is vital that the resulting role is one that can be trained for.

Assumptions about this division are being made at the moment and are affecting how NATS plans and implements projects but these assumptions are not being made explicit. If the assumptions prove to be invalid then system validation might prove invalid.

The changing division of responsibility between the machine and the human needs to be defined clearly and explicitly over time and at each key milestone of system operation.

Group Statement 3. The introduction of automation will be neither as safe nor as effective as it could be. Automation could be used to remove risks from the current operation – unless this is done in a focused way (aimed at specific known risks) the full benefit will not be realized and, in fact, automation may add risks. Automation needs to be focused upon removing key risks from the operation and exploiting the different strengths of the human and the machine.

The operational effectiveness of our systems relies heavily upon the close relationship between the human and the machine – if this is not optimized then maximum effectiveness will not be realized. Automation needs to be focused upon achieving the most effective balance between human & machine. The cost/benefit balance of automation needs to be managed.

Group Statement 4. There is no clarity on how the relationship between the human and machine will change due to technical failure (or cyber-attack). Current assumptions regarding the capacity of the human to revert to manual operations are likely to prove incorrect after a short while of automated operations. If this is the case, we might not have a mode to revert to.

It is difficult to place limits on the extent to which automated systems should be implemented in order to ensure that they ultimately remain under human control. In general, the greater the level of automation the further the human is removed from the control loop and therefore the harder it is for them to recover control. The skills that the human will need to exercise in order to effectively participate in Human-Automation interaction need to be identified and the impacts of automation anticipated.

Group Statement 5. Aspects of human behavior indicative of their ability to effectively use future automated systems are not receiving the emphasis required. We do not yet know the number of people and the types of skills/capabilities we will need to provide for the future.

\(^1\) Minimum Operational Performance Standard
ATM changes. These have been planned over the next few years and will require current controllers to significantly adapt their ways of working. The extent to which they will need to be helped to do this will depend on NATS ability to effectively assess their automation “competence”.

Group Statement 6. There isn’t yet an agreed and validated methodology for assuring the performance of the automated system (cooperative performance of human and automated technical system). Co-ordinate/co-operative requirements are neglected. As automation levels increase, the complexity of the emergent system interactions will also increase. Traditional methods of analysis and validation are unlikely to provide sufficient assurance that the system will be stable. It will be necessary to set and measure demanding performance standards for the total system.

NATS is planning for levels of automation that have not yet matured into operational systems. They might not mature. Automation of human-centered socio-technical systems has far reaching consequences that can be framed only at an organizational/societal level (see Rasmussen and Svendung, 2000)

DISCUSSION AND CONCLUSION

We looked at NATS current self-reflecting upon automation and its consequences as a case study of engineering resilience against unexpected and undesirable effects of automation. Given the initial stage of the work, our conclusion takes the form of a working hypothesis to be further confirmed. Given the increasing complexities of socio technical systems, traditional HCI and human-automation interaction issues cannot be handled outside a general framework of automation policy. This includes a set of goals, values, costs and strategies to cope with uncertainties and unintended effects of automation. First, NATS needs to address more explicitly what the long term and scope of automation is going to be. This goes beyond a piecemeal approach where automation innovation would be technology and task driven. The latter means that two main rationales for introducing automation is the availability of the technology and a focus on a specific (set of) task under the assumption that intervention on subcomponents of the system do not need to consider the long term effects on the operations in their ensemble. However as we stated, with automation level increases, the complexity of the emergent system interactions will also increase and traditional methods of analysis and validation are unlikely to provide an overall assurance of system stability.

Second given a better specification of NATS requirements and expectations about automation, what will be the range of roles that humans are expected to engage with? The history of automation both in the cockpit and on the ground has shown that humans act as ‘mediators’ (Downer, 2009) between the automation and the environmental contingencies and operational complexities. Typically operators have to monitor for un-expected interactions among apparently unconnected subcomponents. Further they need to reconcile the need for standardization (like the European Sky) with the need to locally tailor tools and procedures.

Third, what sort of competencies will be required; how they will affect the selection process; the training and the maintenance of them has to be informed and guided by a policy of automation. This goes beyond the specific characteristics of the system in use. For example, a recent study by Amaldi & Rozzi (2012) has documented that in the case of a National Service Provider, a vision of automation has affected decisions about changes on a specific interface and thus about competencies required in an interim phase.

Fourth, safety has reached level that can be hardly improved through the development of further safety nets alone. Rather the roles played by the various agents across the organizational levels of control have to be openly discussed, identified and defined.

Last we include in the appendix an open ended questionnaire that has been distributed to NATS management and staff. We are seeking further comments on these challenging issues and would appreciate any feedback from this audience.

REFERENCES


Downer, J (2009). When failure is an option: Redundancy, reliability and regulation in complex technical systems. LSE, Discussion paper 53.

ordination. In *Cognition Technology & Work* 4: pp. 240-244


