Putting in Operation a Complex System is not only a Technical Challenge: Transitioning to a newly Automated Environment

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Abstract

This study aims at highlighting the main issues involved in transitioning from a traditional controller's working position to an interactive stripless environment. Self-report and observational data have been collected to capture the knowledge generated by air traffic controllers to manage the transition. Results showed that the transition process was structured into several phases. Further, it was quite successful in as much as the entire population learnt to work with the new system with a fair degree of satisfaction.

In addition, main "automation" issues have clearly emerged and they were quite consistent with those highlighted by the literature on cockpit automation. They included need for reconsidering information processing, problem-solving and co-operation strategies, and for working out shortcuts to compensate for system deficiencies. Task allocation and responsibility sharing were other issues considered. In addition, learning material appeared to be quite unsatisfactory from the standpoint of air traffic controllers having to learn a new system.

Introduction : ROME'S NEW AREA CONTROL CENTRE

With the realization of the new hall of Rome's Area Control Centre (ACC), ENAV has begun the global transformation of the Italian system for the management of en-route air traffic. This will allow ENAV to satisfy the traffic demands of the next ten years and to count on state-of-the-art Air Traffic Management.

The new technological system, known as ARCA (Advanced en-route Centre for Air traffic management), meets the following requirements:

- data integration
- multifunctionality
- modularity
- flexibility
- expandability

as foreseen by the European program for integration and Harmonisation of Air Traffic management systems (EATCHIP).

The Rome ACC is one of the four Italian Centres for the control of traffic overflying the country and has jurisdiction over the airways network comprised between Sardinia, Sicily the Island of Elba and Apennine Mountain Chain.

STRUCTURE AND CARACTERISTICS

The new system has been designed and developed by ALENIA MARCONI SYSTEMS in consortium with Vitrociset and IBM Italia

The heart of ARCA's operations, situated in a control room of about 1900 square meters is made up of: four big control areas, expandable up tp eight, 32 control suites (each composed of three workstations) for monitoring the corresponding sectors in which airspace can be divided. The four areas are controlled by 24 computers on which software requiring over 1.3 million lines of instructions runs.

Every suite is capable of handling simultaneously, the position data of 600 (versus the previous 200) aircraft (radar targets) The data are coming from 12 en-route radar (7 in the old system). Every suite, which host a three-person work-team, is equipped with monitors (CDS 2000) having an extremely high resolution. This allows the simultaneous presentation of radar flight, meteo and monitoring data, that in the previous system, had to be obtained from various sources.

With respect to the previous system (named ATCAS), which is a "stand alone" system, ARCA achieves the automated integration with other Italian and foreign Control Centres having the same high level of technical innovation.
In fact, ARCA adopts standard communications protocols; the ASTERIX protocol which allows telematics sharing of data arriving from the same data used for the control of en-route air traffic. ASTERIX also allows for the OLDI (On Line Data Interchange) protocol, which enables the telematic exchange of data pertaining to flights transitioning from one Centre to another. This results in a noticeable disburdening of the workload between control centres and an increase of capacity whilst maintaining the same safety standards.

Furthermore, it will be possible to update ARCA (which is a modular system), and to adapt it to an additional traffic demand. In addition to this, its flexibility allows for the smooth reconfiguration of the sector into which airspace is divided. When necessary, the system can even allow the management of routes pertaining to another ACC.

Finally, the data banks contained in the central computers (Radar Data Processing and Flight Data Processing Subsystem) are replicated in each workstation, thus obtaining a high data redundancy.

OPTIMIZATION OF CONTROL PROCEDURES AND SYSTEM FUNCTIONS

The optimisation of air traffic control procedures, achieved through the use of the new integrated system, is even more evident with the new man/machine interface which is surely its most innovative element.

ARCA's different functions can, in fact, be present simultaneous on the monitor:

- Visualization of the radar data (position of an aircraft in every instant)
- Visualization of the flight plan data
- Generation of maps, for example transformation of a NOTAM(Notice to Airman) into a graphic indication
- Verification of the operational status of remote and local navigational aids (NAVAIDS)
- Interactive management of flight plans and "silent handover" of control responsibility of an aircraft from sector to sector (silent handover is the name

given to the automatic transfer which is different to the previously done by voice)

- Diagnosis of clearance given by the controller
- Chromatic identification of the flight status of single aircraft.
- Visualization of meteorological information
- Prediction of the flight trajectory with on-screen presentation
- Graphic depiction of potential traffic conflicts or penetration of areas classified as restricted/prohibited/dangerous
- Electronic management of the strips.

Background

This work represents an initial step towards highlighting the adaptation process occurred during transitioning at the Air Traffic Control Center (ATCC) in Rome-Ciampino (Italy) during the years 1998 and 1999. Controllers transitioned from a "manual" non-interacting working position into a stripless, partly automated environment. Following results from the literature on automation in the cockpit (Billings, 1997; Woods, Sarter & Billings, 1997), it was hypothesized that the introduction of several automated functions accessible through the radar image, would profoundly affect controllers' working methods, including information processing strategies and cooperation.

Referring to the context of the present study, one broad difference between the old environment and the new electronic environment can be described as it follows. Several different kinds of information previously accessible through different sources (e.g., telephone calls, oral communications, flight paper strips) have now been integrated into a computer based representation. However, changing the way of representing the information means to change the nature of the problem and thus the kinds of strategies that can be used to solve the problem. The influence of computer based representation has been well underlined by several authors (Woods, 1995; Woods, Johannesen, Cook,& Sarter, 1994). Observations carried out in different industrial milieu have shown that the use of computer as a medium for representation has to be considered in the light of the goals and task context of the team of practitioners. Our observations aim at highlighting the consequences of the introduction of new ways of representing the problem context.

A number of studies on cockpit automation indicated that a lot can be learned form operators once the new technology has been integrated into the working environment (Sarter & Woods, 1992, 1995; Wiener 1989; Wiener & Curry 1980). In that respect, the verification and validation of a new system should not stop once it becomes operational, but it should continue well after the operators have started using the tools. And this is because the effects of automation can be best understood while observed as a part of an environment, not just as the result of operator-machine interaction. Therefore, we consider that the ideal unit of analysis is the human-machine-environment system (Flach, Hancock, Caird, & Vicente, 1995). A broader unit of analysis has to lead to the definition the scope of automation or the *validity domain* of the system (Amaldi, 1999). Such a notion has to be expressed with reference to the set of strategies and tasks characterizing controllers' activities. The validity domain of a function includes those tasks and subgoals previously accomplished by the operators and now taken up by the new automated function. This analysis aims at highlighting which aspects of those tasks accomplished by the function are still left up to the operators and which enter into the validity domain of the system. Making explicit the validity domain of any new tool will help the operator to better understand what they can expect from the machine and what is still left entirely up to their responsibility.

Finally we would like to explore how automation changes the production processes considered from an organizational standpoint. Industrial high risk processes such as nuclear power plants, air traffic control, surgery operating room, nuclear weapons system are characterized by being *tightly coupled*, i.e., their component parts are quite dependent upon one another (Perrow, 1984). As a consequence a change introduced in one component propagates to others affecting the whole production cycle. For this, deviations from standard are quickly noted and responses to deviations must be standardized and immediate. The main features of tightly coupled systems can be summarized as it follows:

- They have time dependent processes: they cannot wit or stand by until attended to.
- The operating sequences are quiet invariant, B must follows A otherwise the production will be impaired.
- The overall design of the process allows only one way to reach the production goals, i.e., they have "unifinality".

While loose coupling systems tend to have ambiguous or perhaps flexible performance standards, "equifinality", that is many ways to reach the goal, continuous processes, such as air traffic control, require a rather tight coupling. Errors quickly propagate and unexpected interactions among the interconnected components might lead to undesirable, if not disastrous, consequences. In other words tight coupling carries a price to be paid for high efficiency. We believe that introducing automation equals to tightening the connections between sub-processes and making the operation rules more clearly defined but less flexible.

Objectives

Transitioning is considered here from a collective and from an individual standpoint. In both cases knew knowledge concerning the use of the new system has been generated by the population involved. The present study represents only an initial phase of the complex process leading to understanding the consequences related to introducing a new technology and new working methods in the domain of air traffic control. Our data come from two levels of analysis. From a macro level the present knowledge acquisition effort will cover an initial description of the "transition" stages as they have been conceived and implemented collectively, i.e., by all of the parties involved (upper management, supervisors, air traffic controllers, software engineers). From micro level, more fine grained observations have been carried focussing on single working teams. The aim is to capture the knowledge expressed in terms of human factor issues needing further attention mostly from a design and from a training standpoint. In particular, this knowledge acquisition effort aims at highlighting how the new technology has been integrated into the current practices of air traffic control and, by the same token, how air traffic controllers have adapted to the new technology. As a by-product of this knowledge acquisition effort, we plan to develop a questionnaire based on the main topics emerged during the study.

Method

Literature review and our previous experience (Amaldi, Gardner-Bonneau & Roske-Hofstrand, 1994; Cooke, 1994) indicate that different types of verbal protocols (concurrent, autoconfrontation, and semi-structured interviews) are a valuable method to elicit expert knowledge (Hollnagel, Kaarstad & Lee, 1999). However, for more reliable results, self report data should be integrated with non-subjective observational type of data. For this initial study we relied mostly on self reported data supported by some on-line observations. The data collection were structured into two phases.

Phase 1: *Off-line interviews*. In order to capture this knowledge, ten air traffic controllers have been interviewed over a number of issues. The format of the interviews was quite unstructured initially, to identify more specific topics to be further investigated during the second phase. A subset of controllers interviewed in this phase was also observed in Phase 2. Interviews were audio taped and later transcribed.

Phase 2: *On-line interviews and observations.* They were carried out to provide:

a. concrete cases concerning those topics identified during the interviews (phase 1);
b. to observe what were the actual responses of controllers in the new environment;
c. to identify new forms of adapting behavior that has not been previously elicited

For this phase, five teams of controllers were observed while managing real traffic scenarios. The observer interacted mostly with the planner controller because it was widely acknowledged that the automation greatly affected the role and task of planning controllers. The remarks of controllers were audio taped and transcribed.

In the middle of Phase 2, an interview session was carried out with a team of system engineers that have been involved in the design of the new system. The objective of the interview was to ask engineers their views about specific topics emerged during previous interviews with air traffic controllers.

Verbal protocols have been firstly read to identify major automation issues. Once the issues have been defined, the protocols have been coded separately by two people.

Results

This section is organized into two parts. Firstly the phases involved in the starting up of the new system will be described and then the main topics emerged once the system was fully operational will be outlined.

Transition and Training

Transition from the old to the new system was a stepwise process, roughly characterized by the following phases:

- 1) Initially care was taken by few experienced controllers to select a group of controllers (about 20% of the entire population) that seemed to be "open" to innovations and at the same time willing to consider possible changes to improve the system.

- 2) *Familiarization*: This selected group of controllers worked initially in a shadow mode. While the traffic was managed through the old system (by "active" controllers), these ("passive") controllers were updating the new system following the control orders issued by the "active" controllers. This made it possible to verify that the new system behaved as expected when given the relevant input. At the same time the group of "passive" controllers got familiar with the system and started to note changes to be made in accordance with their operational needs. These changes would then lead to an improvement of the human-machine interaction.

- 3) *Learning*: Once this group learned how to interact with the new system, they played the role of "tutors" to the remaining controllers still working with the old system. The latter started to manage the traffic during off-peak hours (night shifts) while being coached by the "tutors". Gradually the controllers started to manage traffic at busier hours till they made the full transition in the new control room. The old system is currently operating as a back up.

Last but not least the training material was insufficient. The documents available were written from a software engineer perspective thus not really taking into account the learning needs of controllers. Thus further attention should be devoted to designing training material that effectively assist controllers in exploring the functions of the new system.

Another topic that did not receive adequate attention was the consequences of automation on the allocation of tasks and responsibility. Having an interactive radar display allowed the radar controller to have access to those co-ordination functions that, in the old environment, were exclusively up to the planning controller. On the other hand the replacement of paper strips by electronic strips made a number of information less accessible to the radar controller. As a result we observed that the radar controller had to query the planner about decisions that in the old environment were available through inspection of the paper flight strips.

Throughout all of the phases controllers noted necessary or desirable changes some of which have been implemented before the system became fully operational. In the section discussing the on-line interviews, some of the requested changes will be identified.

On-line and off-line interviews

Before discussing the interviews carried out with controllers, we shall make a few remarks concerning the session held with the team of system engineers. The discussion was centered on design topics identified by air traffic controllers during Phase I and II. A main conclusion was that there was a marked difference about the view hold by the team of engineers and the controllers about the system. From a system engineers perspective, the main reference is the system and the operating procedures have to be adapted to allow the most effective use of the system. In addition as it has been confirmed by the literature, system engineers seemed to have a very simplified model of the operators' activity structure. Form the operators' perspective the starting point are procedures and goals to be achieved, and the system should be adapted to their current ways of accomplishing their tasks.

During the on-line and off-line interviews, controllers stated that the new system allowed them to manage more traffic with an increased level of comfort. In fact while the safety level was maintained, the new system allowed controllers to face a double challenge: the increase in traffic demands due to the war in the Balkan area and the high traffic peak reached during the summer season.

However, controllers have also emphasized that the process of verifying and validating the new system was still going on as they did not feel they have tested all of its properties under a variety of conditions. Controllers repeatedly stated that practicing in the actual environment enabled them to identify "mismatches" between features of the system design and characteristics of the task environment. Constraints and advantages were often identified by comparing the new to the old system. Among the advantages, controllers remarked that the introduction of digital automated co-ordination in most cases facilitated their task. They also appreciated the clarity of the radar image and the use of colors even though, as we shall see later, those were at times misleading.

Some constraints were more critical than others thus interfering with the normal operations and flow of activities. For example, if an aircraft significantly deviated from its planned trajectory, the system would not "recognize" its actual position unless it was updated by a certain time. Failure from the system perspective, to accept as valid the true route of the aircraft caused controllers to revert to a "degraded" mode of control involving the execution of several actions which, at busy time, could interfere with the normal flow of operations.

Among the changes induced by the automation, controllers referred to the cooperative strategy, task allocation and planning. The new interactive interface required the development of new resource management strategies, if its advantages were to be fully appreciated.

We shall now detail five major areas, identified by controllers characterizing new forms of operator-machine-environment interaction.

- *I Automation introduces a new "co-operating agent" into the team*

The first general remark was that controllers admitted that one of the main differences between the "old" and the "new" system was the less individual variability tolerated by the new environment. A number of procedures previously accepted and shared by the community became inadmissible once the new system has been introduced. This is because automation introduces new working methods that need to be acknowledged and followed for productivity and safety to remain the same or even to improve. In other words, automation can be thought of as a new co-operating agent provided that human operators comply to the "rules of the game".

In addition to the new rules, controllers have to take into account that for any task, be it planning, conflict detection, co-ordination, at this time there no automated tool is designed to take into account the entire complexity of any of these tasks. Defined in terms of the operator's activities, there is only a sub-set of goals that, for any task, is achieved by the automation. As a result, controllers might be faced with a number of situations for which there is no new procedure as these situations fall outside the scope of the automated function. In fact for any automated function its *validity domain* should be defined in relation to the sub-tasks comprising any complex activity from the operator's perspective. For example, in the present study, cases have been observed where the new procedures to carry over co-ordination were not enough to accomplish the task. In fact controllers had to "manually" (i.e., orally) negotiate, as part of the co-ordination task, with the neighbouring sector, at which time the coordinated aircraft had to be transferred. Thus negotiating transferring time falls *outside* the validity domain of the automated co-ordination function of the present system.

- *II. Integration of the Flight Data Processing (FDP) Server and the Radar Data Processing (RDP) Server.*

This is, may be, one among the most important design issues needing further consideration. Two separate windows on the same screen (for the planner controller) are dedicated to the display of data coming from, the FDP and RDP servers respectively. However only the information coming from the RDP including the actual position of traffic, is a truthful representation of the reality, at least with a very high degree of reliability. Other information presented on the radar screen (and thus to the executive controller as well) are reliable only if the system has been updated following all of the necessary inputting actions. This information includes the predicted trajectory, flight color indicating whether the a/c will be entering the sector, or coordinated flight levels appearing on the electronic strip bay (not presented to the executive). Thus controllers have to be aware that information having the same form of presentation, does not have the same degree of reliability. From a human factors perspective, this put additional attentional demands on the controllers. Further integration of the FDP and the RDP will have several beneficial consequences:

- Late updating of the aircraft trajectory would be "accepted" by the system without requiring redundant inputting actions.
- A new coordinated flight level would be received by the interested sector even though the later is different from what was anticipated by the original flight plan (PLV).

- Automatic propagation of the new flight profile will imply a more reliable information associated to color coding of the traffic. In that respect, it was observed that some "white traffic" (that is not expected to enter into the sector) was indeed going to enter into the sector and interfering with traffic already assumed. This caused some late avoidance maneuvers.

- *III. Color coding*

Colors are used to identify the status of the aircraft. In the actual system, a main distinction is made between "green" and "white" traffic. The latter one is not supposed to get in radio contact with the sector and thus it should be regarded as uninteresting. As such, the color coding of the traffic is a filtering device whose objective is to assist controllers in focussing their attention by "filtering out" irrelevant information. However because the reliability of a filtering device depends on the accuracy of the information fed into the system, this reliability is threatened by erroneous inputting actions. Further, the logic commonly developed to interpret the output of any filtering device is that an information is relevant *if and only if* it is highlighted by the automated filtering function (double-implication logic). Any other information can be disregarded. This has several unwarranted consequences, like the well known phenomenon of "tunnel vision" (Moray, 1981) leading operators to disregard relevant information that was in the background. An alternative approach would be to interpret the filtering device according to a simple-implication logic. That is, if an aircraft is highlighted then it is relevant, otherwise it remains up to the controller to check whether it might be appropriate to give special attention to it or not.

- *IV.* Oral versus digital communication

Co-ordination, which in the old system was carried out through telephone calls, has been replaced by digital communication. This is true for co-ordination carried out inter-sector or between Centers equipped by the OLDI system. From a human factors perspective the following consequences have been observed.

- Oral co-ordination implied an immediate acknowledgment and updating of the flight profile. Communication, be it face-to-face or through telephone calls had a *dynamic constraint* as the receiver had to reply on-line to the sender of the information and made the necessary changes on the flight paper strips. By consequence, the planning controller asking for a new co-ordination level would obtain an immediate answer and the reassurance that the receiver would be aware of the change of the flight profile.
- Further, upon receiving the new co-ordination level, the planning controller would pass the information on to the next sector who would do the same with the planning controller of the next interested sector and so on and so forth. Thus oral dynamic communication somewhat compels operators in taking the necessary actions for keeping all of the concerned parties informed.

- On the other hand, digital communication has an intrinsic delay of reply. Such a delay has been considered also for data link communications between controllers and pilots (Sarter, 1997; Podiani, 2000). This means that the receiver might take several seconds or even minutes to answer the digital message. In addition, for the present study, it has been observed that the new coordinated level is not as regularly propagated to the interested sectors as it was in the oral communication condition. This has several undesirable consequences as described in paragraphs II and III.
- Sending a digital co-ordination message in the new environment has two different consequences according to the time of sending. If a new coordinated flight level is communicated when the aircraft is quite far from the target sector (i.e., before the aircraft enters into the "sending" sector), then the sender does not need to wait for acceptance of the new flight profile just sent to the next concerned sector. Thus sending a digital message equals to carrying out the co-ordination. On the other hand, when the concerned aircraft is already in the sector requesting the new coordinated flight level, the latter has to wait for an "acceptance" from the receiving sector. In this latter case, sending a co-ordination message does not imply that the co-ordination has been achieved. Controllers have often remarked that sending a digital message was sometimes considered as accomplishing the co-ordination regardless of the time at which the message was sent. Thus attention was not always given to receiving the acknowledgment from the next sector.

V. Conflict detection in a (paper) stripless environment.

Introducing the electronic flight strip has changed the way controllers looked and planned for future conflicts. In the traditional paper strip environment, flight strips were ordered in a bay to allow the planning controllers to "scan through" them following a sort of pattern matching search. For example it was enough to read on two strips that the related aircraft were expected to be at the same point at approximately the same time, to trigger the detection of a possible interference. Special marking on the flight strips served as memory aid concerning the type of conflict and the solution. At the same time this information was easily accessible to the radar controller as the content of the paper strips was clearly readable. In the electronic environment the way the electronic strips are displayed does not allow for this sort of economic and efficient pattern matching search. The planner controller has look for conflicts by scanning the radar screen. The flight profile of each aircraft has to be compared with all the others and no simple heuristic is available to limit the searching space. In principle all of the aircraft entering the sector (but not only, see paragraph III) can interfere with any other. As a consequence we have observed that the planning controllers does not use the radar picture and the functions included with it to do long term planning. They rather wait for the aircraft to enter the sector and apply a more tactical, rather than strategic, way of solving future interference. Due to difficulties in planning the traffic with electronic strips, most controllers we have interviewed expressed the need to have a tool designed to help them in identifying future conflicts well before the aircraft enter into the sector.

Conclusions

A first sound observation is that the system, overall, has been successfully integrated into the ATC environment. This conclusion is supported by controllers' statements expressing appreciation for the features of the new system, and by objective data showing that while traffic load and complexity has increased, safety has maintained its previous level.

This work started out with the aim of capturing knowledge developed by air traffic controllers during the transition from a "non interactive" working position to a partly automated controller's working position. While this should be considered an initial effort to describe the nature of the operator-machine-environment interaction, our data allowed us to highlight a number of human factor issues needing further consideration. The interest of these findings is that they come from an environment where the technology has been introduced since about a year. Like for those studies carried out in the cockpit (Wiener, Chidester, Kanki, Palmer, Curry & Gregorich, 1991) the issues emerged reflect the testing of the technology in the actual operational environment.

Two main features of the new environment seemed to originate a number of important consequences. First of all, the old environment was characterized by the existence of multiple sources of information each one having a distinctly different status. Having integrated most of this information into a single computer display has created the impression that the nature of the data displayed is the same while it is not. Thus the reliability of the radar data track is very different from the reliability of the trajectory shown for each aircraft entering the sector. For the latter case, an erroneous inputting action is enough to make the projection of the trajectory wrong. Controllers remarked that sometimes the truthfulness of the information appearing on the electronic flight strip window was regarded as being the same as that coming from the Radar Data Server.

Further the replacement of paper with electronic flight strip has made a number of information and cues unavailable to the radar controller. In this case, the introduction of a computer-based representation has eliminated a means of communication between the members of the same team. This findings parallels what has been observed in the glass cockpit (Sarter & Woods, 1995). The introduction of the Flight Management System has eliminated a number of cues that were successfully used by the crew team members to infer what actions have been taken by the other member and thus assess the status of the flight. In both the ATC environment and in the cockpit, the introduction of automation meant the need to stress the importance of oral communication between the team members.

From the planner controller's perspective, the introduction of the electronic flight strip has shown to deeply change the nature of the planning task. First of all, it has eliminated a very economic strategy for identifying potential future conflicts. The simple pattern matching heuristics afforded by the paper flight strip bay, has become impossible in the new computer-based representation. The consequence is that in many cases, the planning of future traffic, as intended in the old environment, has been virtually replaced by tactical strategies. An important remark is that the new representation did not eliminate the information available in the old environment, but it simply changed the format of such information making its access more cumbersome. According with the literature on problem solving, this implies that changing the way of presenting the information might deeply affect the way of representing and solving the problem (Simon, 1969; Woods, 1995).

These findings taken together indicate that the display of data through the medium of the computer should be considered in terms of how different types of representations vary in their effect on the operators' problem solving behavior and co-operative strategies. Thus a full appreciation of the properties of computerized systems has to seriously take into account what are the new requirements introduced by the new technology. In our cases, controllers agreed that the new system need to be integrated by a tool that would make planning easier

Overall, the introduction of automation has made the system more *tightly coupled* than in the old environment. Regarding co-ordination, for example, controllers seemed to be aware that the procedures to be followed were more invariant and reduced in number with respect to the old system. This implied that an erroneous inputting action would propagate through sectors or even through Centers. Tightening the system implied also making the process more time dependent: certain actions not only had to be executed in a specified order but also at a precise time for the system to achieve its goals. Invariant sequences, time-dependent sequences and "unifinality" are some of the central features characterizing tightly coupled systems (Perrow, 1984). For this, while controllers recognized that new system allowed managing an increased amount of traffic, they also observed that recovery from errors was much reduced with respect to the old system. Like for loosely coupled systems, controllers remarked that before automation was introduced, there was a better chance that expedient, individual short-cuts could be found even though they were not planned ahead of time. There was a general feelings that more redundancy should be designed in the system to make error recovery easier.

Controllers observed that introducing digital communication makes available to the radar controller certain functions that were accessible only to the planner. Thus task allocation and sharing of responsibility have to be reconsidered following the introduction of automated functions.

This study highlighted some of the consequences related to the introduction of automation. Automation has changed the way of representing the problem, it has introduced new working methods and thus it has potentially affected the way of managing resources. This can be seen by considering how planning for future conflicts has changed in the new environment. Long-term conflict detection has been replaced by a more short-term, tactical recognition of conflicts. Based these findings, as preliminary as they might be, we are in the process of developing a questionnaire that should capture the issues controllers showed to be more sensitive to or those issues that are believed to be critical for the efficiency and safety of the system. The results of the questionnaire taken together with the present findings will serve as a basis to formulate recommendation for improving design and tailoring training.

To conclude it is recommended that the "automation" issues identified by this study (e.g., information processing and co-operative strategies, sharing of responsibility, learning strategies) be considered in a more explicit way. This should happen before introducing automation rather than just wait for the operators to work out their own "integration" strategies and learning methods. A more conscious consideration of these issues has the advantage, among others, of reducing the number of changes to be made once the system is fully operational. Further principled training methods can be designed, including preparing the operators to what they should expect from the automated system. For this we would like to emphasize the relevance of a recent co-operation effort between the Italian Administration and Eurocontrol in the area of prototyping. If pursued by the Italian Administration, the project, ITI (1999) would allow the testing of future tools in a simulated environment thus making the testing of several options feasible. Given that the ATC system is in the process of undergoing major innovations the opportunity to simulate different scenarios seems not only desirable but necessary for being prepared to face major challenges ahead of us.

Reference

Amaldi, P. (1999). *Le rôle d'un modèle du diagnostic dans l'évaluation d'un système d'aide à la décision dans le contrôle aérien: Le cas d'ERATO*. (The role of a diagnostic model to evaluate a decision support system: The case of ERATO) Doctoral dissertation, University of Toulouse-Le-Mirail.

Amaldi P., Gardner-Bonneau, D., & Roske-Hofstrand, R. (1994). Acquiring and representing knowledge in the domain of Airway Facilites. Paper presented at the *First European Conference on Cognitive Science in Industry,* Luxembourg: Centre de Recherche Public - Centre Universitaire.

Billings, C.E. (1997). *Aviation automation. The search for a human-centered approach*. Hillsdale, N.J.: Lawerence Erlbaum Associates.

Cooke, N.J. (1994). Varieties of knowledge elicitation techniques. *In International Journal of Human-Computer Studies*, 41, 801-849.

Flach, J., Hancock, P.A., Caird, J.K., & Vicente, K.J. (Eds) (1995). *Global perspectives in the ecology of human-machine systems*. Mahwah, NJ: Erlbbaum.

Federal Aviation Administration - Human Factors Team (1996) *The interface between flightcrews and modern flight deck systems*. Washington, DC: US Department of Transportation.

Hollnagel,E., Kaarstad, M., & Lee,H-C. (1999). Error mode prediction. In *Ergonomics* **42**(*11*), pg. 1457-1471.

ITI (1999) *Danish & Swedish Interface Italian Controller Evaluation*.

Moray, N. (1981). The role of attention in the detection of errors and the diagnosis of failures in man-machine systems. In J.Rasmussen,& W.B. Rouse (eds). Human detection an diagnosis of system failures. New York: Plenum Press. Pp. 185-198.

Woods, D.D. Johannesen, L.J. Cook, R. I. & Sarter, N. B. (1994). *Behind human error: cognitive systems, computers and hindsight*. Cseriac: The Ohio State University.

Perrow, C. (1984). *Normal accidents. Living with high-risk technology*. Basic Books.

Podiani, F. (2000). Controller's operational perspective of CPDLC. Paper presented at the *Controller-Pilot DataLink Communications Symposium*: Rome 25-26 May.

Sarter, N.B. (1997). Communication technologies and procedures in support of future Air Traffic Management (ATM) operations. In R.S. Jensen, & L. Rakovan (eds.) Proceedings of the Ninth International Symposium of Aviation Psychology, Columbus: Ohio , pp. 1476-1480.

Sarter, N.B., & Woods, D.D. (1992). Pilot interaction with cockpit automation: Operational experiences with the flight management system. *The International Journal of Aviation Psychology, 2*, pg. 303-321.

Sarter, N.B., & Woods, D.D. (1995). "How in the world did we get into that mode?" Mode error and awarness in supervisory control. *Human Factors*, 37(1), 5-19.

Simon, H.A. (1969). *The sciences of the artificial*. Cambridge, MA: MIT Press.

Wiener, E.L. (1989). *Human factors of advanced technology ("glass cockpit") transport aircraft* (Technical Report 117528) Moffet Field, CA: NASA-Research Center.

Wiener, E.L., & Curry, R.E. (1980). *Flight-deck automtion: Promises and problems*. NASA Tech. Mem. 81206, Moffett Field, CA: NASA-Ames Research Center.

Woods, Johannesen, Cook,& Sarter, (1994).

Woods, D.D., Sarter, N. et Billings, C. (1997) Automation surpises. In G.Salvendy (ed.) Handbook of human factors and ergonomics. New York: A Wiley Interscience Publication, 2nd edition.