Analysis of Requirements for the Human Machine Interface of Airport Traffic Control Systems

Prof. Gaspare Galati *Ing. Antonello Tassi*

Department of Computer Science, Systems and Production Engineering (DISP) and Vito Volterra Center

Tor Vergata University
Via del Politecnico1, 00133 Rome (Italy)

Phone: +39-06-72597417
FAX: +39-06-72597532
E-mail: galati@disp.uniroma2.it

Abstract **– In this paper a Human Factor study of an HMI (Human Machine Interface) for airport surface traffic control systems will be introduced. The most important part of this study was developed in the "Marco Polo" airport, Venice, Italy. The Agencies involved in the surface airport management traffic are ENAV (Ente Nazionale di Assistenza al Volo) that is responsible for the traffic in the movement area (runways, taxiways, connections) and manages the controllers in the Control Tower and SAVE (the Management Society of this airport) that is responsible for parking and safety in the Apron. The study was centred on the users of the system, i.e. controllers (ENAV) and operators (SAVE) and its main target was the determination of requirements for the HMI in order to improve safety and efficiency in the airport traffic and to make easier the management of airport traffic in a full optics involving all agencies co-operating in the airport. The overall aim of the HMI is to improve the co-operation between different operators to improve safety and efficiency in handling of aircraft and service vehicles in every visibility conditions.**

I INTRODUCTION

A Surface air traffic control and the transition from SMGCS to ASMGCS

The management of airport traffic today is done by the so-called SMGCS (Surface Movement Guidance and Control System).

SMGCS is an integrated system of functionalities, equipment, operative procedures and operators that, according to the ICAO regulations (doc 9476-AN/927), must carry out the follow tasks:

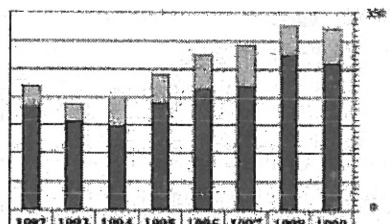
1) To prevent collisions on the airport surface, in other words to guarantee safety (there is a slight, continuous increase of runway incursions, see figure 1);

2) To guarantee an orderly and expedite flow of the airport, in other words to guarantee efficiency.

The success of the SMGCS depends, also, on the cognitive abilities of operators (attention, memory, judgement, decision making ability, problem solving ability, ability to organise) and, in particular, to the traffic situation awareness, today mostly based on what controllers see from the windows (glass walls) of the Control Tower.

Of course, the main requirements of surface traffic control, safety and efficiency, are conflicting. In fact, an absolute safety is only obtained moving aircraft one by one in every visibility and traffic conditions, while efficiency needs to move as many aircraft as possible at the same time. Therefore, airport management is the best trade-off between safety and efficiency.

The long-term continuous increase of air traffic has brought to the congestion of the SMGCS which, today, is essentially manual.



	1992	1993	1994	1995	1996	1997	1998	1999
Totale	219	186	200	240	275	292	325	321
Piloti	37	28	51	50	60	73	51	61
Veicoli	92	84	66	125	146	132	183	182
Ctr	90	74	83	65	69	87	91	78

Figure 1: Increase of the number of Runway Incursions in the ninety's (Source: F.A.A.)

In particular, limitations of the SMGCS are evident in low visibility conditions in which controllers could not see any aircraft (in this case are used very restrictive procedures that impose 4 or 5 movements per our) and also in high traffic (in large airports there are peaks of 70 or 80 movements per hour). Both cases require an important cognitive engagement for the operators.

Moreover, the management of SMGCS is complicated to the airport infrastructures (Air Terminal, Hangars, stores etc.) that obstruct the sight of significant portions of the airport surface to the controllers, also in good weather conditions. (See figure 2).

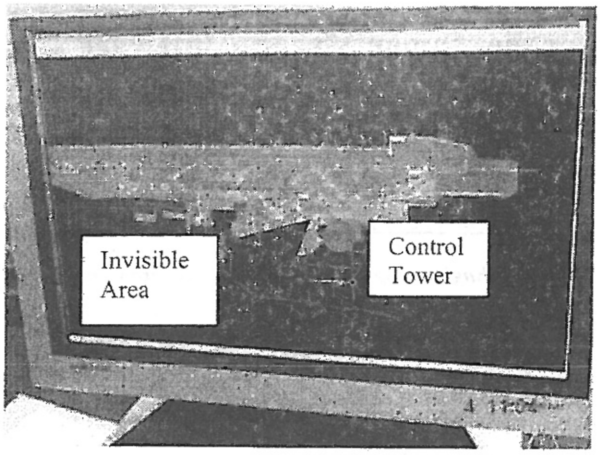


Figure 2: Visibility of Apron from the Tower of "Marco Polo" airport (Venice).

Figure 2 shows that the necessary expansion of the airport infrastructures is in conflict with the needs of traffic control because it obstructs controller's view. In particular, the new Air Terminal of the airport "Marco Polo" of Venice obstructs the view of about 1/3 of the Apron from the Control Tower.

Introducing automation and data fusion in SMGCS should enable to reduce controller's cognitive engagement and support safety and efficiency. A modern airport traffic management system would be centred no more on the need to see traffic especially from glass walls of the Control Tower but, in low visibility conditions, the traffic situation would be available on the HMI.

This new airport traffic management system is called A-SMGCS (Advanced Surface Guidance an Control System); it is aimed to reduce, as much as possible, controllers' mental workload that is rather high actually. This is very important because stress is one of possible source of risk for safety and efficiency.

Reduction of the controllers' mental workload can be reached through realization of a suited HMI capable of showing the controller the situation on Runways, Taxiways and on the Apron. This presentation has to be not ambiguous and, eventually, enabling to foresee conflicts between aircraft or between aircraft and service vehicles through particular algorithms.

Now we want to point out the importance of realizing automated system centred on the user and, therefore, not autonomous nor silent (i.e. that do not let us known what the system itself is doing). In other words, the users has to be the solver of conflict situations, and the system has to support them during execution of their tasks, for example offering a clear and not ambiguous vision of movements in all surface airport. This is necessary because surface traffic is in continuous and quick evolution and its variables are numerous. Therefore, for traffic administration we can't trust exclusively on automated system, based on algorithms previously defined, but it is necessary to use human analysis ability.

To obtain the best results is necessary to harmonize at best the automated system capacity and the human cognitive ability: automated systems must be designed so as to be a valuable support for operational users' needs.

The Human Factor study of "Fast Prototyping" project was aimed just in this direction.

B The "Fast Prototyping" project

The Human Factor study has been part of the context of the project called "Fast Prototyping". This project has been developed in 2001-2003 in the "Marco Polo" airport, near Venice, by a temporary association of three Bodies: two Industries: Oerlikon Contraves, Thales ATM and the "Tor Vergata" University of Rome. Consignee of the project was ENAV S.p.A. (Ente Nazionale Assistenza al Volo-Società per Azioni).

The "Tor Vergata" University has done the scientific direction of the project.

The Fast Prototyping project has included the implementation of an A-SMGCS system (Advanced Surface Movements Guidance and Control System) of Level 1 (automation must carry out detection and identification of aircraft and vehicle either co-operating or not co-operating) and the use of an high-resolution SMR (Surface Movement Radar), operating at 95GHz and with a resolution of 3m x 3m at 900 m from the antenna, and a Differential GPS system.

The main objective of the "Fast Prototyping" project was the analysis of operational use of modern A-SMGCS technologies with a lot of attention to the display of data to the operators (ENAV and SAVE) including the raw radar video, the symbols and the labels.

C The Human Factor's team activity

The Human Factor's team was constituted by Dr. Paola Amaldi, as consultant of the University of Rome "Tor Vergata", and Ing. Antonello Tassi, under supervision of Prof. Gaspare Galati.

From the beginning of this study the Human Factor team has avoided the "Hard" approach (that identifies "prescribed" target for the operators) preferring the "Soft" approach.

The literature about "Soft" methodology points out that analyses of requirements for software or other system development (new procedures, reorganizations, training etc.) have to be preceded or accompanied to the analysis of the operators' "purpose" that are developed locally, by operators, to allow an efficient administration of the system in all of its extent but often are in conflict with the prescribed targets of the system. In fact, purposes reflect the necessity of the operators to adapt really available resources to the operational context. In other words, the "Soft" methodology permits to analyse a lot of "scenes" of the same reality and allow pointing out different sources for definition of requirements for new systems (Kotonya & Sommerville, 1998).

Several "points of view" permit to point out the conflict between the general "purpose" as declared by the airport administration and the local "purpose" that single entities follow in their normal activity (Checkland, 1999).

The literature distinguishes between "purposes" developed locally by different subsystem and "target" that represent the overall target declared to all component of the system.

The literature about social-technical systems has pointed out repeatedly that all staff implicated in the administration of such systems should develop some strategy and shrewdness that facilitate fluidity of normal actions but on the other hand may originate errors and difficulties.

Rasmussen (1999) uses the terms "finishing the design" meaning that operators complete the functions of the technologies (or other resources) adding other functions not foreseen during the planning of the system.

In short, this study is justified, among other things, by the following hypotheses:

- The distinction between "prescribed" activity, or "target" of the system, and "real" activity, or "purpose", implies the recognition that every complex and safety critical system inevitably produces inside some conflicts and tensions that can affect safety and efficiency. It is important to point out that operators have to manage not only the attainment of the target of the system but also conflicts or paradoxes generated inside the system.
- The above hypothesis, applicable to every social-technical system, is a starting point for the system analysis from the Human Factors point of view. This approach involves observations of the operators during their normal development of tasks. One of the aims of the team was to point out the presence of conflicts between "targets" and "purposes". The analysis was not aimed to point out "weaknesses" of the actual system, but, rather, to tune and realize the capabilities and features offered by the Fast Prototyping system in order to fulfil the real operational needs and to define the most suited requirement for the HMI.

D Modality of Human Factor study

The Human Factors study has been divided into 2 main phases.

In the first phase the basic knowledge has been developed about the operational environment, with focus on key problems about surface traffic control and visits to the visits in the Control Tower of the airports of Fiumicino (Rome) and Venice.

In the second phase the team has analysed the Human Factors of the HMI of Fast Prototyping in Venice airport and precisely in the Control Tower (ENAV), in the SAVE-Safety premises and SAVE-CDS office (ramp and parking activities). SAVE is the Society that manages the infrastructures and some services of airport and holds SAVE-Safety, a society responsible for the movements in the Apron and their safety, and SAVE-CDS (Coordinamento di Scalo), a society responsible for parking and ramp management.

The interviews of controllers and operators of Venice airport characterized this second phase, for better understating of the problems focussed in the first phase and also to discuss matters proposed by interviewees.

About 50% of the whole controller/operators staff in Venice airport was interviewed, in details: 16 controllers from ENAV, 7 operators from SAVE-CDS and 5 operators from SAVE-Safety. But actually, the Human Factors team has received the opinions by 100% of people, due to his continuous presence in the airport for more than 5 months, making it possible to discuss with all operators also out of the interviews.

There is another phase, overlapped in time with the other two, i.e. the analysis of data acquired from time to time.

In every visit (first and second phase) it has been possible to interview and to observe the activity of operators and, above all, how they co-ordinate their activity between each other and with other agencies involved in the management of the traffic.

The information have been collected in the following forms:

- TV video tapes;
- audio recording;
- written text.

Audio recordings have been transcribed or reassumed.

II MAIN PROBLEMS ANALIZED

Complexity of surface traffic management implies a lot of problems. In the following the most meaningful ones related to the HMI realization are discussed.

A Presentation with "raw" Radar signal

The Fast Prototyping system has two main sensors, i. e. a new high-resolution radar (the 95 GHz miniradar) and a D-GPS (Differential Global Positioning System).

The technical characteristics of this Surface Movement Radar (SMR, main parameters: time duration of pulse 20 ns, azimuth resolution 0.2 degrees) allow displaying the raw signal on the HMI used by the operators.

So one of the problem studied by the team analysing of Human Factors was just the comparison between raw display and synthetic display, this last being widely used in actual HMI of A-SMGCS system, taking into account of the operational necessities of involve persons.

Is necessary specifying something before describing this part of Human Factor study. A lot of controllers interviewed, in their professional life, knew only synthetic presentation and the other usually worked with raw presentation but using air-traffic control radar (not SMR) whose resolution cell is larger than the targets of interest.

Every interviewee considered synthetic presentation more "clean" and easy to read than raw display, but finally raw display was considered fundamental. In fact, the synthetic presentation, that we can consider "aseptic", imply a filtering of some property of the radar image of aircraft presented and an interpretation of the image that not always would be considered reliable.

Operators sad that filtering and interpretation of image is much reliable if is performed by human in the operational context instead than by predefined algorithms.

All interviewed (100%) have chosen the raw display instead of the synthetic display, but some explanation is needed with respect to accept this restrictive condition.

When an operator was in front of HMI, with the raw display, he had always the same behaviour. Precisely we can identify 3 different phases that characterised all the interviews concerning raw video versus synthetic radar display.

In the first phase controllers and operators shows an evident *confusion* for the raw display. They sad: "... all is confused..." "... gives an effect of disorder... " or "... I don't understand at all ...". This was comprehensible because raw display, differently to synthetic display, might not be easily red and must be interpreted. So it was necessary devote some minutes to provide controllers and operators main elements useful for the correct interpretation of raw radar images.

At this time it was taught to the interviewee the phenomenon of radar shadow that can hide parts of a target. Was taught that radar show only half aircraft like an human eye, for example if the radar antenna sees an aircraft on the right its left wing can be masked. The controllers learnt that the shape of objects (aircraft in particular) change with reference to their orientation and the point of view of the radar. When this point was accepted, what required only few a minutes, the second phase began.

Second phase was characterised by interviewee's *curiosity*. They realized that they could see all parts of the airport (Apron, Taxiways and Runway) also even though boundaries of the objects were vanished. Some controllers were very surprised to see luggage trolleys parked under the Control Tower that they had never seen before.

Besides, they were surprised to see a lot of vehicles moving in the Apron and to recognize some of those with an illegal speed.

Controllers showed a good ability to discriminate cars and tanks truck using their different dimensions in the raw presentation.

Another cause of surprise was possibility to see "cinesini" (light on the boundary of Taxiways and Runway) and signs near Taxiways.

At this point of the interview, controllers began to appreciate very much the raw display, accepting presence of a vanished boundary of objects to have a complete display of all it was happening in the airport.

For every aircraft was recognized easily the prow (direction on which the aircraft is oriented), also if aircraft was stopped, and the category (small, medium or heavy).

Besides, in this second phase it was asked to the interviewees to recognize the model of the aircraft looking only the screen of HMI. We have noted that controllers recognized easily MD-80 and ATR-72 because they have a peculiar shape (the wings in particular). But some common Airbus or Boeing aircraft could not be distinguished because of their similar form.

The third phase was characterised by the *approval* of raw display. In this phase it was carried out the comparison between raw display and synthetic display. Practically, the interviewee (who have had some knowledge about raw presentation) saw the same scene in raw presentation and in synthetic presentation, and was asked to make a choice. Every time the choice was for the raw display.

The following sequence of pictures will show this very important phase of choosing the raw presentation.

Figure 3 shows the real situation. Holding Point (called B1 and B2) are taken to an ATR-72 (white aircraft on foreground) and to a Boeing-737 (yellow aircraft on back ground)

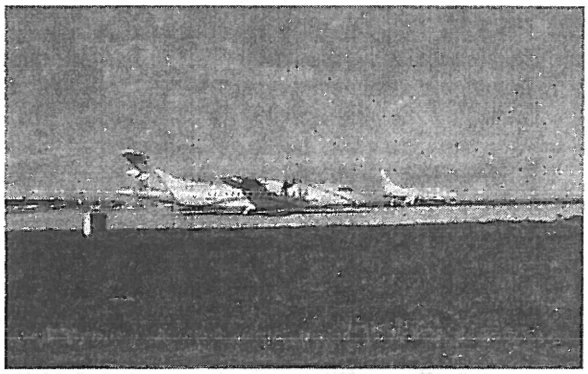


Figure 3: Aircraft waiting in the Holding Point called B1 and B2 (Marco Polo airport).

The same scene of figure 3 was showed on synthetic presentation (see figure 4) and on raw presentation (see figure 5)

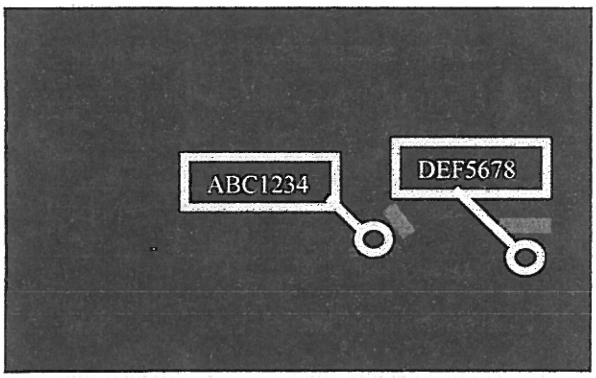


Figure 4: Synthetic display.

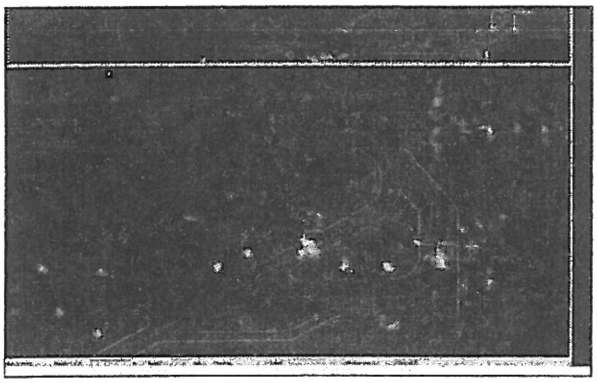


Figure 5: Raw display.

All interviewee, looking synthetic display, said they preferred raw display for its richness of details. For example synthetic display can't show vehicle that haven't a transponder on a board.

Besides, operators have realised that synthetic display shows only essential information about movements and omits all the other. This limitation wasn't accepted.

Also if the raw presentation is preferred to the operators, we have to say that synthetic presentation is more clear then raw presentation. Therefore a possible solution consists of the overlap of raw presentation and synthetic presentation, as shown in figure 6.

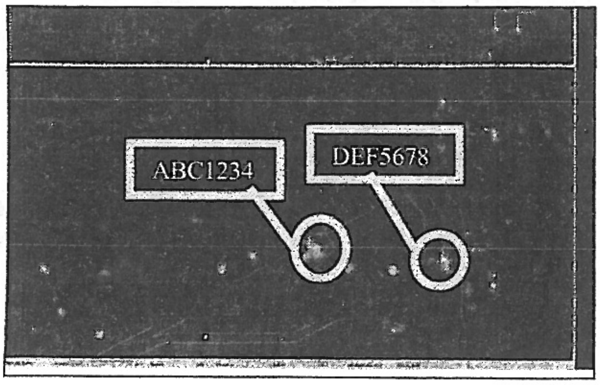


Figure 6: Synthetic information overlaid to raw radar video.

This kind of display is useful because it joins the best characteristics of the raw and synthetic display offering to the operator the most complete visibility on the airport and the possibility to recognize, looking at the HMI, the conflict situations (and probably to project forward this situation) and the aircraft that need more attention.

B Co-operation between different operators

Another matter that we have considered with attention is the use of this HMI to improve co-operation between operators from different organizations, i.e. ENAV and SAVE as briefly described above.

During this study we have noted that every organization must respect precise rules necessary for the attainment of the required levels of safety and efficiency. However, both organizations work in an unrelated mode and, some times, they became an obstacle for each other even when respecting proper regulations. This happens because the infrastructures of the airport are used to a big number of operators with different purposes and knowledge.

There are various problems related to this situation and we think that a particular use of the HMI can solve some of them, as shown in the following example, probably the most significant.

Problem of this case concern the so-called "optimisation of departure series". Generally the sequence of Take-Off is fixed with the FIFO logic (First In First Out) but in high traffic conditions controllers want to minimize the average-delay for departure and then, when pilots of aircraft ask for "Push Back" approval (it is not a "clearance") and depart from the parking area, they arrange a particular sequence for departures that depends to a lot of factors, for example category, speed, destination etc. In this procedure aircraft can take-off more quickly and average-delay is reduced. Practically the controller who approves "Push Back" puts this request in the group of all requests previously considered and mentally fixes the best sequence for take-off.

But in the airport of Venice all aircraft moving in the Apron must be preceded by a "Follow Me" (managed by SAVE Safety) from parking to Taxiway or vice versa.

The problem is just the lack of co-ordination between controllers, who define the sequence of departure, and operators of the Follow Me, who escort aircraft from the parking. In fact controllers (ENAV) do not inform the operators (SAVE Safety) about which aircraft has to be escorted by a Follow Me or about the departure sequence.

Therefore operators of Follow Me have no chance to know the planned departure sequence nor they know that controllers are building optimal sequence, so they consider only their experience and when they notice that an aircraft is ready to move immediately they escort this aircraft to the Taxiway. Often the operator's choice doesn't coincide with the controller's choice.

In practice operators of the Follow Me make the actual departure sequence and the most peculiar aspect of this situation is that operators don't know that they are the main actor of creation of the sequence. So, above all in high traffic conditions, seldom an optimal sequence is used.

The HMI of the Fast Prototyping can supply a valuable help to the co-ordination if every operator of Follow Me is equipped with a vehicle with HMI aboard. The HMI has to be connected via air LAN to the FDP (Flight Data Processing, is a system located in the Control Tower and used only by controllers).

When a pilot asks approval for initial moving from the parking (or when he is moving in direction of the Holding Point), controller must put in the FDP sequence the departure of that aircraft. This information will be shown on the HMI of Fast Prototyping so it will be visible also for operators of the Follow Me, in order to allow they to know exactly which aircraft they must escort firstly (see figure 7).

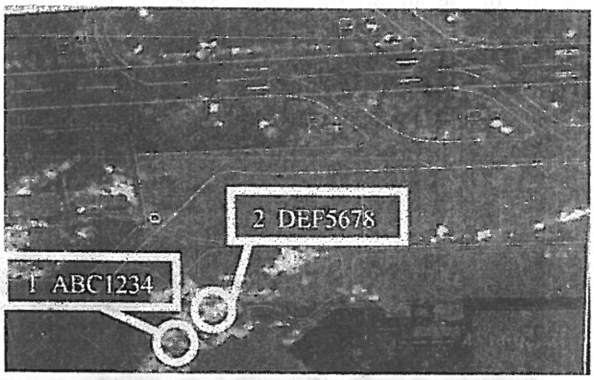


Figure 7: Example of co-ordination between controllers and Follow Me operators.

From the example in figure 7 we can see that the label of the aircraft in their parking don't show only the name of the flight, for example ABC 1234, but in front of the name is located a number that describe just the position for this aircraft in the best sequence of departure. This information can be shown easily to the Follow Me operator who have

HMI aboard whit a positive contribution to the efficiency of airport traffic management.

This procedure does not increase controllers' workload: in fact today the controller must put information about departure in the FDP system.

C Number of windows in the HMI

The last theme of this paper considers the choice of the optimal configuration (in particular quantity and utilization of the windows) to use on the monitor of the HMI.
Two kinds of monitor were available, one 24" for the controllers (ENAV) and another 17" for operators (SAVE, Safety and CDS).
During interviews we have noted that most person preferred two horizontal windows (see figure 8)

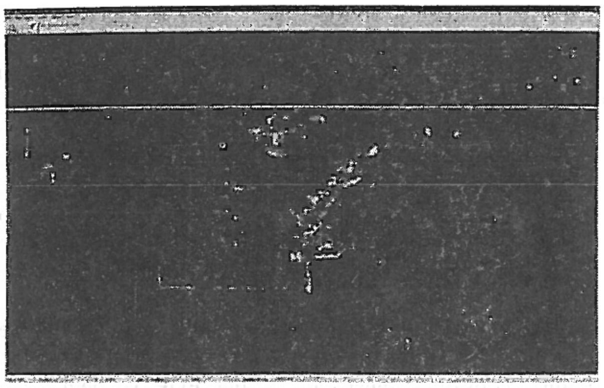


Figure 8: Display of Marco Polo airport using two horizontal windows.

In the top window controllers put Runways and Taxiways, and in the bottom windows, the full Apron; the layout of the airport of Venice is easily shown in two windows.

Three controllers have proposed a different configuration of the windows.

One has preferred to use three windows, one for Runway and Taxiways and two for Apron (subdivided in Apron North and Apron Sud).

An example of this configuration is in Figure 9.

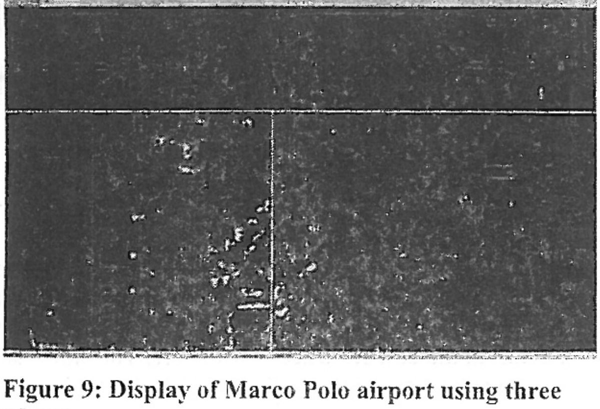


Figure 9: Display of Marco Polo airport using three windows.

Other two controllers, with a big experience in the use of radar for air-traffic control, have chosen to change the presentation as a function of visibility. They want a configuration with two windows (figure 8) in good visibility conditions, but they prefer a presentation with two windows (see figure 10) in bad visibility. This is justified to minimize risk of confusion using two windows.

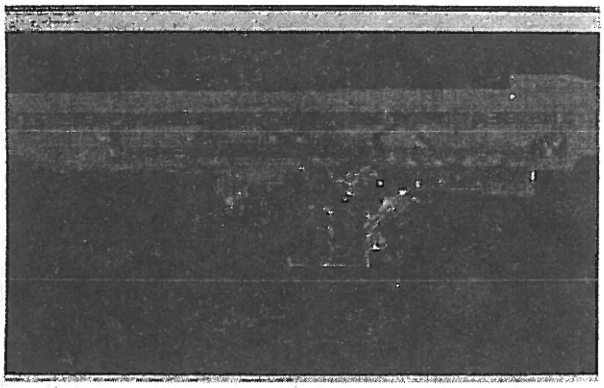


Figure 10: Display of Marco Polo airport using a single window.

The choices by the SAVE operators resulted the same as ENAV controllers (see figure 11).

SAVE operators had a smaller screen (17") than controllers' screen (24") but they don't want to give up to all airport surface visibility, with Runway and Taxiways.

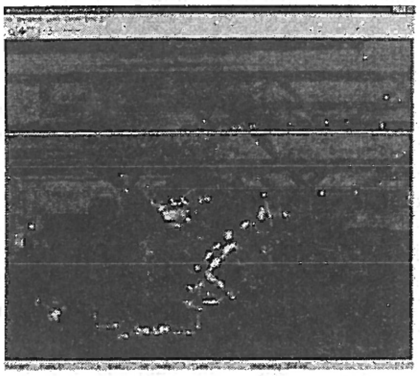


Figure 11: Display type as selected by SAVE operators.

The Human Factors team considered very interesting the equality in the choice of controllers (ENAV) and operators (SAVE). In fact, controllers and operators have very different tasks and responsibilities. Controllers (responsible only on Runway and Taxiways) want to see also the Apron, while operators (responsible only in the Apron) want to see also Runway and Taxiways.

Equality in this choice is ascribed to the awareness of controllers and operators that need complete information about surface traffic to perform correctly their tasks, also in areas in which they have no responsibility.

III CONCLUSIONS

This study points out that realization of new technologies and their insertion in operative sectors must be joined by the knowledge "on site" about real working activities by operators who will use this technology. The whole activity of this study has highlighted a multitude of themes, three themes in this paper being only an example.

An overall result of this research is the recognition of the need to improve communication and co-ordination between controllers/operators belonging to different organizations as well as the sharing of the same "situation awareness" of the whole airport.

IV ACKNOWLEDGEMENT

The authors want to thank ENAV S.p.A. for supporting and permitting the Fast Prototyping study and the Companies Oerlikon Contraves Italiana (Rome) and Thales ATM (Milan) for the signals and the data used in this study. The contribution by dr. Paola Amaldi to the Cognitive Engineering methodologies is gratefully acknowledged.

V REFERENCES

Amaldi, Galati, Tassi, (2004). "I Fattori Umani nel progetto Fast Prototyping" Centro Vito Volterra- Rapporto tecnico (in italiano).

Kotonia, G. & Sommerville, I. (1998). "Requirement Engineering: Processes and Techniques". John Wiley & Sons.

Checkland, P. (1999). "Systems thinking systems practice. A thirty-year perspective". Chechester: Wiley.