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Coordination and Collaboration Environments for Production Lines: A User Acceptance Issue

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Abstract. The Airbus Visual Line (AVL) project, now deployed on the A380 assembly line, was propelled by the desire to foster collaboration and coordination among aeronautical Final Assembly Line teams while going beyond the simplistic – repressive concept of "andon boards" (Monden, 1993). We introduced an environment composed of large public displays and semi-public interfaces to support this collaborative process, so as to enhance team awareness and facilitate coordination among the multi-disciplinary actors. Acceptance of such a coordination system on the shop-floor is a difficult issue. The difficulty is mainly due to the increasing complexity of sub-systems to assemble, the increasing amount of teams involved, the ever-shortening time to market and the circumspection of all actors regarding a 'monitoring' system. This article proposes solutions to facilitate team acceptance in the design of highly distributed coordination environments. The acceptance challenge is developed along three major factors, information targeting, information clarity and privacy concerns. From the points it develops, this article aims at facilitating Computer Supported Collaborative Work (CSCW) environments development in complex coordination system such as industrial production lines, building and construction sites, large naval or aeronautical maintenance contexts.

Introduction

Industrial production lines are seldom considered in the CSCW literature about collaboration and coordination, but they are an extremely relevant field of study. A first reason is the exponential complexity of the products manufactured, which requires an ever-increasing range of expertise during the production phase. Large teams from different technical backgrounds are involved all over the manufacturing process. Another reason is the reduction of time to market, which forces formerly sequential activities to be performed synchronously by different teams. Furthermore, tasks are growingly interdependent, and one's activity can be influenced by the activity of other teams. Therefore, coordination on the production lines is subjected to several issues: distribution of the information space all over the shop floor and sometimes over several factories, huge size of this information space, heterogeneity of the actors' background and interests, and interdependencies within the information space.

Existing coordination systems, mainly developed throughout the 70's, have targeted the resolution of isolated problems (Monden, 1993). Those alarm systems have gained the negative image of a repressive system among the shop floor actors: one of activity monitoring and repression of faults. Evolution of current production practices towards complex distributed tasks and closer relations between operators and support team forces coordination systems to shift towards more comprehensive and less repressive collaboration and coordination processes. Therefore, acceptance of the distributed coordination environment among the different actors becomes a complex challenge when designing for the shop-floor.

Based on a concrete project now deployed in the largest factory in Europe, the Airbus A380 final assembly line, we claim that the acceptance of a distributed coordination environment is driven by three major criteria:

- **Information targeting** – how to define a consistent information transfer to very different teams and hierarchical levels in different locations?
- **Information legibility –** how to transmit highly detailed information, such as a plane assembly planning, to a large audience distributed in a huge area?
- **Information privacy –** how to convince end-users that a dynamic coordination system is not aimed at monitoring their activity?

This article reports on our experimental study of these criteria through the Airbus Visual Line (AVL) project. This project, which went through a research phase in 2002 and 2003, was aimed at enhancing coordination among distributed teams on the assembly lines. Its success led to its industrial deployment in 2004.

The next section looks at related works and existing frameworks for all three criteria. We then describe the aeronautical final assembly lines, set the scope of the study, and introduce the AVL environment. The three following sections develop each of the three criteria through their application within the AVL environment. The last section presents the results of the research project, based on field observation and questionnaires, to assess the level of acceptance reached through the application of the three criteria to the AVL project.

Related Work

Background: Shop Floor Coordination and the Andon 'Alarm' Systems

The use of public displays in the manufacturing process has generally focused on efficient notification of periodic production line failures to the support teams, thus facilitating coordination over simple sequential operations. The *andon* system (Monden, 1993) made famous by Toyota is simply a way to report the occurrence of a problem on the assembly line ('andon' is the Japanese for 'signal'). In case of a problem the operator pulls an alarm string and an electronic board is activated. Typically a yellow signal indicates a problem (missing part, defective assembly, etc) and a red signal indicates the problem is so severe the operator has to stop the line. The team manager or the support team then comes for assistance.

The andon system left a very negative image, because whenever an operator has to pull the andon string, the whole line is stopped and the faulty operator is pointed out by his co-workers. Human contact and solidarity are very important factors on aeronautical assembly lines. A repressive system, or an environment assimilated as a monitoring system by end users, would thus not be accepted on the shop-floor. Respect of information privacy is always a very delicate point for public systems (Jancke et al., 2001; Tollinger et al., 2004). User acceptance regarding privacy issues is certainly the most sensitive and delicate aspect to be considered during the coordination and collaboration environment design.

Targeting Large Distributed Groups with Public Information

Many studies have addressed the need to support collaboration and group-based activities using large interactive displays. Early projects, such as LiveBoard (Elrod et al., 1992), focused on supporting collaborative activities through large electronic whiteboards using novel interaction techniques. Those works have been extended in more recent projects by embedding several interconnected displays in the environment to support more complex collaboration activities. Examples as iLand (Streitz et al., 1999) and iRoom (Johanson et al., 2002) proposed complete interactive environments and investigated novel ways to share information and control between the multiple displays during meetings.

Another approach has been to use large displays to support communication and coordination of groups and teams. Several projects augmented notice boards and bulletin boards found in community areas, thus focussing on the communal spaces rather than the whiteboard in meeting rooms. For example, Plasma Poster (Churchill et al., 2003) and Community Wall (Grasso et al., 2003) were designed to enable people to post and annotate information onto a large public display available to a community of users.

Other applications have exploited the large displays to promote shared awareness by making the information of other's activities available to a community of users. The Notification Collage (Greenberg et al., 2001) and the Semi-Public Display (Huang et al., 2003) augment features associated with community notice boards with an aggregated overview of the activities of a community of users. Kimura (McIntyre et al., 2001) makes a user's current and past activities available to others. Those systems use large peripheral displays to provide background awareness of activities that users have performed.

The use of large interactive boards in communal spaces, or "public" spaces, also found application for "walk-up and use" collaborative activities. The Blueboard (Russel et al. 2002), and its modified version for NASA space mission scientists: the MERBoard (Tollinger et al., 2004), enables identified users to quickly display, manipulate and exchange personal information available on the network. The Dynamo (Brignull et al., 2004) further enhances this personalised information sharing capabilities by enabling several users to simultaneously "carve" their own collaborative space in the public interactive surface.

As observed by Xiao et al. (2001) and investigated by all those projects, the large public boards used in communal spaces can support a very broad spectrum of group activities. By using the persistence of information and playing on the ubiquitous aspect of the large-scale displays in the workplace those large displays can induce asynchronous collaboration among groups and enhance coordination. We based our investigations on those findings to design the AVL environment. However, researchers demonstrated that it can be very difficult to get the users to spontaneously use the collective display. Churchill et al. (2003-2) and Agamanolis (2003) found that users were initially reluctant to use the system and needed constant encouragements to interact with it. Jancke (2001), stresses that the quality and adequacy of information conveyed is critical for the environment relevance, and thus to arouse users' interest.

Visualisation of Highly Detailed Information

Andon systems and most coordination systems focus on the notification of single events. This avoids the trouble to transmit the complete information space to the end users and only convey single, uncorrelated alarms. However, Schmidt and Bannon (1992) demonstrated the need to recontextualise information in order to facilitate information appropriation, and this is confirmed by Xiao (2001). The problem faced with production lines is the size of the contextual information to be passed over. Several Human Computer Interface-related studies have covered the issue raised by large and detailed data visualisation. The Perspective Wall (Mackinlay et al., 1991) or the Fisheye (Noik, 1993) involve geometrical deformations of the information representation in order to better visualise details. Baudisch et al. studied focus plus context systems (2002) for cartography applications, potentially usable in a multi-user schema. Their system is composed of a high-resolution display providing focus, embedded in a larger, lower-resolution system displaying the context.

Context of the Study: the Airbus Assembly lines

Our study took place in the Airbus aeronautical final assembly lines in Toulouse (France). On an aeronautical final assembly line, the aircraft goes through several stages before completion (eight to fifteen stages for one plane program). To each stage corresponds a physical station in the huge assembly plant (see Figure 1). The process is not purely sequential: a few dozens of actors team and support each other for executing hundreds of required operations during the several days the plane stays at the assembly station. For each station there are three types of actors:

- the **operators** perform the assembly tasks. Upon day and night shift alternations they take over the tasks left pending by other teams. They may receive assistance from the support teams for specific issues;
- **support team**s, as for andon systems, perform timely interventions for specific actions (logistics, quality, technical issues) signalled by the operators, and assure the action follow-up. The support team's offices are usually located some distance from the station, up to 200 metres in some cases;
- the **station manager** is in charge of the overall station organization. He or she must have a synthetic view of the current station status as well as an insight of the prospective organization of the station.

Figure 1: Airbus A380 assembly line station number 40.

The complexity of this inter-disciplinary relationship, each actor bringing its specific requirements, is the key of the final assembly line coordination. From those inter-dependencies, we have identified the following three main types of information a coordination system should convey:

- *Task specific information (operational view)*: details of the technical tasks to perform (documents, tooling…), specific task allocated resources and status.
- *Notification system (tactical view)*: similar to andon notifications, it deals with isolated events and alarms.
- *Planning management (strategic view)*: visualization of overall progress, actions follow-up and impacts forecast; it is the longest term view.

The Previous System

A paper-based coordination system is currently used on the lines. A0-sized pages display a very detailed planning of the tasks to be performed on the station. The planning is called a *balancing,* because it results from a process of evenly distributing the tasks across the available work time and technical competences. It is located nearby the station gathering area (see Figure 2). The balancing organises the station operators' activities much like a classical planning would: resources on the left and an associated time line of operations on the right.

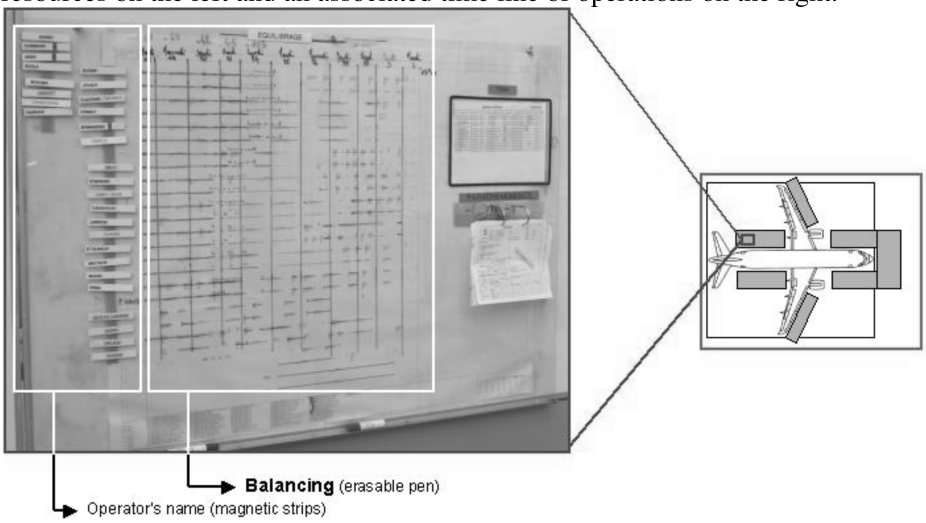

Figure 2: Paper-based coordination system and location on the station

Operators update the balancing by reporting their work progresses with an erasable pen, drawing lines of percentage of work achieved on top of a photocopy of the balancing. The balancing is mostly used by operators, to help teaming and daily planning, especially in case of night and day shifts on a same task. The coordination with other actors is mostly verbal and based on experience. Consequently, operators do not update the balancing very often: between once per day to once per week only.

With that system, a delicate issue for the collaboration is the link with support teams, not only for problem reporting (logistics, technical issue …) but as well for quality checks and validations. Usually, operators facing a problem or needing to validate an operation have to walk over to the support offices, write a report and verbally notify the appropriate support person - if found.

Designing the Airbus Visual Line (AVL)

By timely conveying the relevant information to a large audience, a coordination system could significantly reduce the time loss associated with the search of a person on the assembly station or distant support office for notification of some sort (Monden, 1993). It would also enhance the actors' awareness of each others' activities, giving way to "natural" management and coordination on the station (Xiao et al., 2001), empowering the shop floor with knowledge and a vision of their current activity. The AVL environment was designed based on those concepts, trying to create a common information space from the distributed, overlapping information places (Bertelsen & Bødker, 2001).

The Design Process

Given the complexity of our context, we adopted for the AVL project a strong participatory design strategy. Iterative and participatory design methodologies are not uniformly employed by the industry. Whereas they are used up to the industrial stage in information and telecommunication industries (Lindholm et al., 2003), for complex systems such as control or supervision environments they are mainly used by research centres (Mackay et al., 1998; Da Silva et al., 2000). To our knowledge, the application of a user centred methodology to one of the most sensitive sectors of the aeronautical industry was a premiere. The design process followed four phases:

The first phase of the AVL design has been the presentation of a scale one, low-cost, proof of concept of the envisioned AVL system to the end-users.

Then followed a user centred design phase to determine the AVL functionalities. Through participative design meetings, we illustrated design alternatives and saved a precious time over long, time-consuming debates. Concrete images of the future system interface started to take form in the users' mind. In parallel, semi-structured observation of current work practices helped to define the exact context on the assembly line.

The illustrator phase then saw three AVL systems designed, implemented with the help of a visual designer, and tested on three Airbus final assembly stations for a two-month duration. During this phase a very strong support was provided to the assembly line teams testing the AVL illustrators. AVL functionalities were completed throughout the illustrator phase based on regular meetings with the teams, whiteboard located near the public display for free comments, a continuous follow-up and semi-structured observations. This phase brought invaluable insight on the users' perception of the system and of the users work practices.

Finally, following the experiment, all participants were given a questionnaire to gather their feedback. A discussion of the questionnaire results and of some of the observations and interviews will be given in the Results section of this article.

System Overview

In exploring the current work practices on the stations, we realised that the needs for information visualisation were closely related to the actor's activity and location. Because of the station size, all information is highly distributed: from the operator's location anywhere on the plane, to the management information on the station's gathering area and even to the support offices dozens of meters from the station. As a result, the common information space we designed matches this distributed geography (see Figure 3) by providing relevant common information tailored to the physical place on the station.

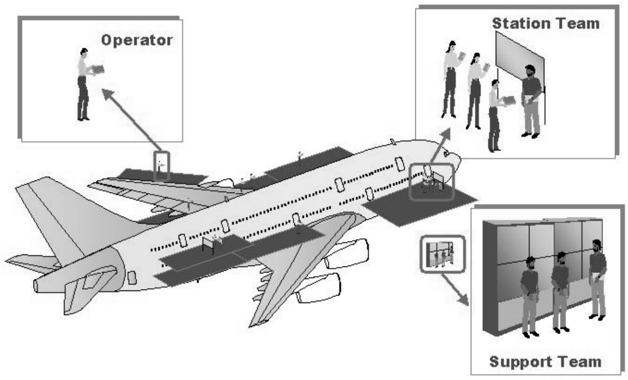

Figure 3: AVL interfaces overview

The AVL environment is based on three major interfaces, all giving access to views of the common coordination space:

- **private input devices**: the primary issue was to enable real time inputs of information on the common information space. A dedicated interface has been designed to enable mobile operators to access and update the coordination space from their location on the station. Using nomadic devices (pen-tablet computer), simple and intuitive interfaces have been designed for declaring the completion of tasks (see Figure 5);
- **large public displays**: what we call the public space is located in an open space, nearby the station and the support team offices. All actors have to pass in front of it to reach their working place. This 2 metres by 1.5 metre retro-projected screen displays a large view (minimum 1600 x 1200 pixels) of the whole station balancing status (see Figure 4). The accessibility of the board, located in a public space, and its size that can simultaneously accommodate several users are key characteristics of a coordination system. The station status displayed is legible from 10 meters to 1.5 meters with different granularity of details depending of the user's distance. Therefore, beyond its use as peripheral awareness display and 'at a glance' overview, the public display can provide highly detailed information on given tasks (task number, percentage of completion, current and past alarms for a given task …);
- **semi-public displays**: Garbis (2000), in the context of control rooms, stressed the use of a large public display as a medium for reference and discussion among team members. Based on similar observations, a smaller shared display was designed to facilitate discussion among teams of operator directly

on the station. Because of their specific location and usage, we refer to Huang et al.'s (2003) definition: "because the information of these displays is intended to support members of a small, co-located group within a confined physical space, and not general passer-by, we call our system a Semi-Public Display." The semi-public displays are 40 inches screens located directly on the station displaying an interactive vision of the coordination space (see Figure 4). Interaction capabilities have been kept very low to privilege the ease of use. A user, through a mouse interface, can browse the planning, zoom and seek for detailed information on specific operations.

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Figure 4: AVL illustrator: Large Public Display (left) and semi-public display (right)

Information Relevance for a Multi-disciplinary Public

Information is distributed on the shop floor. Each actor, by his or her actions, participates to the creation of the common information space. However, depending on their specific role, location and current action, all actors will not need the same view of the information space to perform their tasks. The challenge here is to define the specific information view required for each actor. We focused on the three specific views (or levels) of the common information space: **task specific information** (operational view), **notification information** (tactical view), and **planning management information** (strategic view). By analysing how all actors manipulate each of those three views we identified the distribution of the coordination information in the physical space. Based on this cartography, the contents and location of each coordination elements can be deducted.

Task specific information is typically directed towards operator teams. This information is the core of the coordination system. Observations and interviews showed that operators essentially used task specific information on the station itself. The closer to the operator's workplace, the more detailed the information must be. For instance, specific information, such as technical document for the task one operator was assigned, must be directly accessible on the spot, where the operator is performing his action. It is, as well, directly on the station that the operator can the most easily notify progresses on the task or specify a task status.

On the other hand, on the station's meeting space, where operator teams gather, task-specific information is also used, but only as a reference for discussions. For instance, we observed a team manager and two operators assembled in that space to discuss the daily planning, and seeking the exact reference of a task to support that discussion. Similar situations occurred with station managers about the status of a particular task.

Task specific views can therefore be split in two different uses. The first is directly on the station, where a detailed view must be accessible and information regarding the properties of the task can be modified. The second is on the public and semi-public gathering areas, where references to the task are made, and only the task status is relevant. Therefore, we proposed mobile, personal channels of communication for the operators on the station (see Figure 5) and clear references to the tasks information in the public areas displays. Personal peripheral information channels avoid monopolising public displays for personal information retrieval, and permit nomadic, on the spot information access.

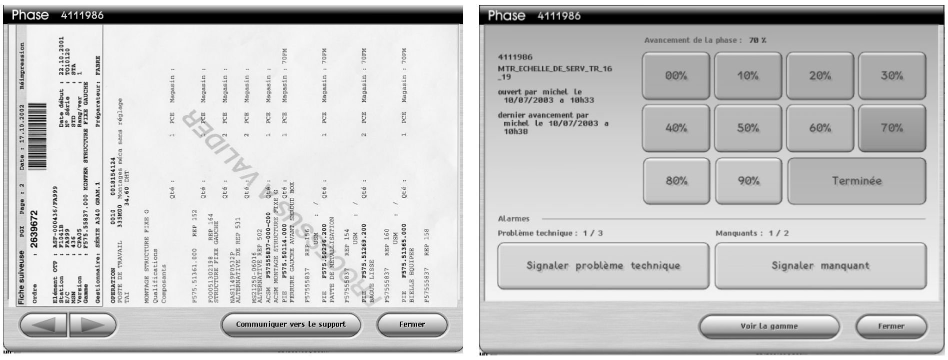

Figure 5: AVL operator interface, for consulting tasks (left) and reporting progress (right)

Notification information, on the other hand, is aimed at the support teams and is, by definition, unpredictable regarding its occurrence. Mc Crickard and Chewar (2003) define this type of interruption as "high interruption", as it should require a strong attention allocation from the user in case of an occurrence. Reactivity is equally expected to be high (a 10 minutes reactivity would be satisfactory), but detailed comprehension is generally not important: the support team only needs to identify the alarm bearer and contact him. We do not expect the support team to seek more details about the alarm on the screen because, as explained earlier, the coordination environment must not substitute to the rich human-human interactions that already exist. Given our notification goals (high interruption and efficient reactivity), McCrickard & Chewar recommend the use of an alarm system. The main challenge for us was to notify the support team in a non-intrusive way for the rest of the station. A non-intrusive parallel notification system, such as a personal beeper, has been envisioned. Still, after participatory design meetings with end-users and management, it was decided that the alarms should be visible by all actors, as for the andon boards systems, and that they should convey contextual information regarding the task and resources impacted. This would allow for a shared knowledge of the ongoing station issues among all support teams.

The AVL balancing interface, publicly visible, provides an implicit knowledge of all station actors' activities. This mutual knowledge gives birth to a "natural" coordination. We observed for instance support teams prioritising their reaction to alarms depending on the task's impacts on the balancing, or notifying another support team that one of their alarms was on. The public display alleviates much of the burden of a centralised coordination by facilitating the direct management of interdependencies.

The third information view, **planning management**, is based on the two previous information views combined with the time and resources allocation. It is essentially directed towards the station managers, even though all actors use this view as a public awareness system. We identified two main usages for the planning view. The main one is the "at a glance" usage, in order to grasp a global vision of the station status. Such a vision should be easily accessible by all actors; we chose to make it available in the public places through the large public displays. The second usage is for discussions and reference regarding the station organisation. This usage requires a more detailed vision of the planning view and usually involves several actors. The closer to the product, the more task-related the discussions become. This is the justification for the semi-public displays. The semi-public displays, located directly on the assembly station, facilitate more operational discussions than the large, public displays. They enable more detailed views and interactions with the task specific views, while keeping a contextual overview of the planning management.

Regarding the specific information the planning view should convey, Reddy et al. (2001), in the scope of a medical coordination system, stress the importance of retrospective and prospective representations of the same information for a coordination system. In our case, the global view of the balancing, displayed on the public screens (see Figures 4,6), offers a clear global vision of all tasks status, fulfilling the retrospective requirement. Additionally, the interface must convey three types of prospective view of the same balancing:

- *The moving timeline*: enhances the time/progress perception indicating the percentage of work achieved and objectives at that time.
- *Upcoming issues anticipation*: expected supply delays notified ahead of time by the logistics support team.
- *Visual impact of current alarms*: based on the balancing critical path, if an important task has an active alarm on, all of the impacted tasks are highlighted on the interface.

Once defined, the three views must be appropriately conveyed to the end users through the environment's interfaces. Problems arise there, particularly regarding the **legibility** of the large public displays. Indeed, several layers of detailed and complex information must be merged into a single view. The next section discusses the design challenges faced when displaying large, detailed information for heterogeneous groups.

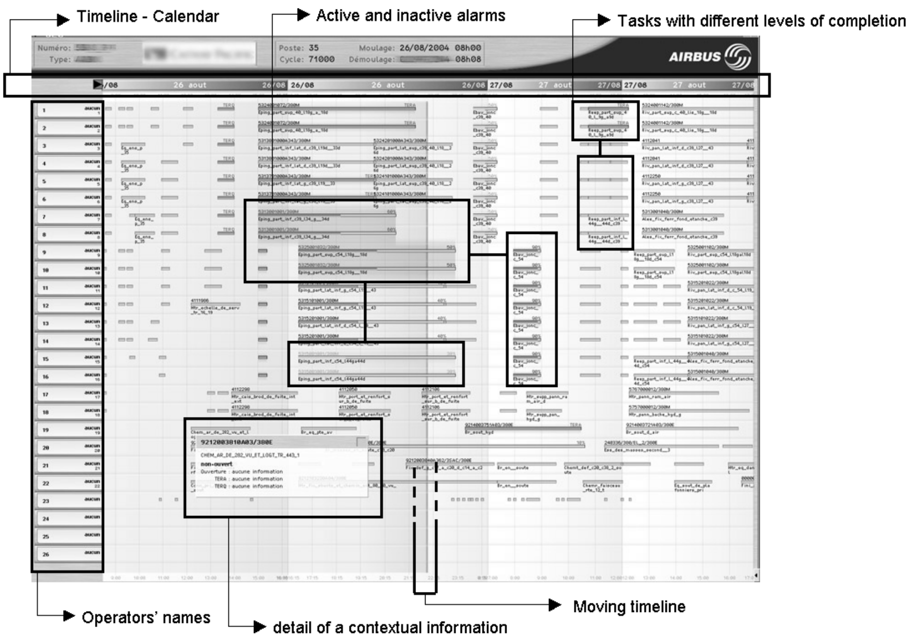

Figure 6: The AVL public interface layout

Targeting Large Groups with Detailed Information

Problems faced when designing distributed coordination interfaces are essentially due to two factors: the huge size of contextual information to display on the public interfaces, and the combination of several layers of information. This section details the solutions proposed for both issues.

Displaying Highly Detailed Information

The balancing, or station planning, is made of thousand of operations allocated to the station teams. Unlike classical planning the station balancing is almost never completed linearly. Some operations may remain pending at the early stages of the balancing while, for logistic priorities, some minor operations planned for the end of the balancing may be completed in an early phase. On top of that come foreseen supply issues on upcoming tasks and pending minor technical alarms. Therefore, to offer a synthetic view of the station, i.e. the contextual overview, the whole station status must be displayed on the public interfaces.

An AVL particularity was the collective use of the large data set to display. After experimenting different HCI solutions with end-users, we eventually proposed a design inspired from Noik's Fisheye view (1993) (see Figure 7). The fish-eye geometrical distortion is limited to the time axis, thus facilitating the horizontal correlation between the resource – operator's name – and a particular task-line. In its "normal" configuration, when no one is interacting with the public display, a fisheye-view of the full station balancing is displayed, centred on the present date and time. This configuration allows any passer-by to see the current station status as well as a detailed view of the same day tasks.

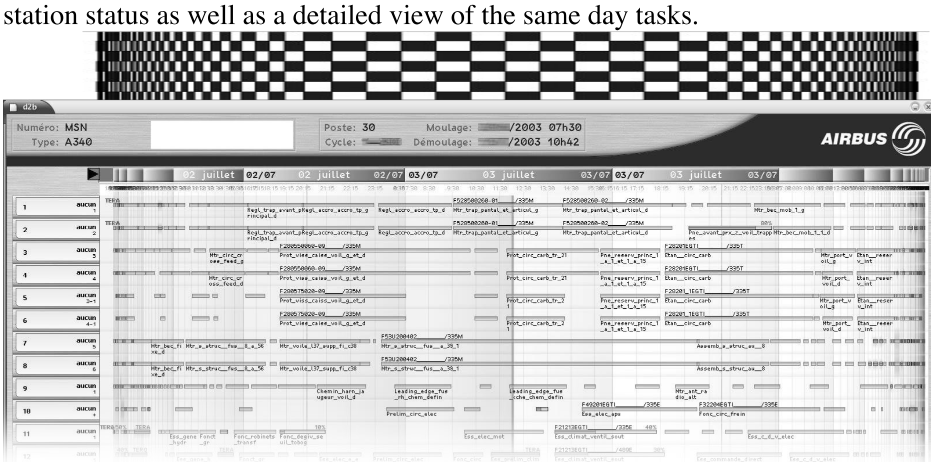

Figure 7: (above) adapted Fisheye Principle, (below) Fisheye view of an AVL balancing

Augmenting the Balancing: Combining Several Information Layers

The AVL interface augments the balancing by providing task-specific information: dynamic information about each operation, notification systems, or an omnipresent moving timeline to mark the present day and time. Thus, we have had to propose a visualisation metaphor that would conciliate a detailed view for the person/group interacting directly with the system, together with a general view for passers-by or more remote readers. Moreover, the large public display is intended to be simultaneously accessible by all station members, hence we had to prevent one user from monopolising the public space as was reported by Russell in the BlueBoard experiment (2002). This requirement implies that all relevant information displayed on the public board, i.e. the synthetic station view, should remain as much visible as possible to the audience no matter what specific interaction one user or a team is performing on the board.

We achieved this by limiting the interaction capabilities to non-obtrusive information retrieval, and always displaying the whole AVL planning on the large public boards. If a user asks for detailed information about a task, it should be conveyed in a manner that does not block other users from accessing the rest of the displayed information at a distance. We describe here two design choices, one for task-related information retrieval, and the other for alarm notification.

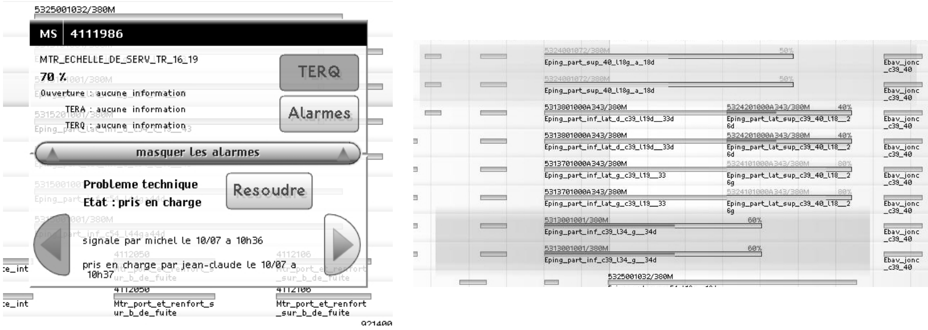

Figure 8: contextual information (left); active and inactive alarms (right)

Information associated to a specific task is frequently used in discussions between team members and management. By browsing the fisheye view, a user can navigate along the timeline to search for a given task reference. This action does not hide the previous and future days for other users, it only compresses parts of the planning on the sides of the board. Once the appropriate task is found, by positioning a pointer over the task, a popup box displays necessary information regarding the task status in a limited space of the screen (see Figure 8). Hence, the global view is never obstructed.

To attract user attention and symbolise the urgency of alarms on an ambient display without using potentially aggressive modalities (loud sounds, strong flashing lights) we proposed to augment the impacted tasks with colour-coded fading rectangles. Whenever an operator signals an issue, the impacted task, on all displays, changes colour – for instance red for technical, yellow for logistics – and fuzzy coloured rectangles centred on the task extend and shrink (see Figure 8). The frequency profile of the animation was adjusted to avoid a stressful feeling when looking at the interface. Then, when a support team member decides to handle the alarm, he/she selects it and signs in. The animation automatically stops, and the colour remains until the issue has been completely cleared.

Acceptance as a Major Challenge

Efficiency, effectiveness and … satisfaction

As discussed in the previous sections we argue that the visual coordination system enhances the effectivity – better coordination – and efficiency – increased reactivity – of the station work. How could such a system not meet user acceptance?

Given the system's dependence to user inputs for its relevance, a problem could emerge if end-users refused to participate and provide information. This would be a sure sign of reject and the system's failure.

We sought to play on several factors to facilitate end-user adhesion. Even though our study occurred in an industrial context, we could not guarantee the system's relevance if it had been perceived as a monitoring system, spying on users' performances. Such an issue can be compared to the public awareness system's privacy issues noted by Jancke et al. (2001). The risk of user rejection had been identified in the early phases of the AVL project. It has been confirmed during the project illustrator phase as several users came to us and raised the question of our exact motivations while we were presenting the system. The main concerns were regarding a fear of activity monitoring, moral harassing and loss of human contact between all station actors.

In order to facilitate end-user adhesion we have used two types of arguments:

- *reflective arguments* explaining the AVL concept,
- *affective strengths* of the interactive system.

Reflective Arguments

No potentially personal information is available through the system's interface. The only information displayed is directly related with the program, excluding competencies, immediate user presence, and all the privacy-related issues.

By setting-up a user-centred design process we sought to facilitate user appropriation of the system from the early phases of the project. Hence, by involving the end-user in a reflection on their own activity, many of them realized the system's benefits and decided to support the project.

The last of the factors has been a strong communication, demonstrating the system's benefits and discussing the potential user reticence. The illustrators were visible by all assembly line teams. The three AVL systems have implemented on three major Airbus final assembly lines stations, each receiving visits from other station operators and team members seeking explanations, offering comments … little by little the idea settled down.

Affective Arguments

From its physical location on the station, the public display is clearly visible by all the station actors and potential passer-by (client, assembly line manager …). Any operator can clearly see his/her name written on the board's line. All active or unresolved alarms denote of pending tasks for the concerned support team. All actors are therefore implicitly involved in the system. This argument is playing on the degree of percolation (Galam&Mauger, 2003) a physical notion used by sociologists, it shows that all actors are directly or indirectly aware of each others' activity, thus creating a web of awareness leaving no room for unwanted behaviour to develop, namely inefficiency.

In order to put forward each actor's role, not only are all displayed information associated with an actor's name, but the system's detail must be carefully chosen: small enough for each action to be visible in the system, but large enough to avoid irrelevant information overflow. Two concrete example to illustrate this idea:

- Task progress detail: operators can only increase task progress by steps of 10%, so that a small improvement in the task progress can be notified at the end of a shift for instance.
- Alarm handling: only two actions are possible for support teams: taking note of an active alarm – stops the flashing – and resolving the alarm – suppresses the highlighting –, therefore no change will be noticed until the problem is completely solved.

Through those incentives actors find a motivation to provide information to the environment, as their contribution to the project is made visible.

Another factor for user acceptation has been the visit of important managers to the station while the system was experimented. Even though this argument only prevails for the experimentation phase, it greatly contributed to the feeling of recognition of the shop-floor and facilitated the system appropriation by the teams.

Finally, in the industrial context, final interface aesthetic is not an insignificant argument for user acceptance. The system's interface has been seen as a projection of the user's own work, therefore nice finishing touches can imply the seriousness of the system proposed and of the user using it. The design of the operator's input interface (see Figure 4) gave a feeling of simplicity and intuitivity to the end-users, hence facilitating their acceptation.

Evaluation Results

The best proof of success of the AVL design is probably its industrial deployment on the A380 final assembly lines, thus validating the end-user acceptance and the AVL environment's adequacy with industrial needs.

However, all over the design process several observations and data collection methods have also been applied. We first describe the results of observations and interviews performed with the previous paper-based system. We then discuss the results of questionnaires filled after using the AVL illustrators.

Before: Structured Observation and Interviews.

Structured observations have been conduced before the first illustrators were set-up on the assembly lines to understand current work practices. Two days of observation of work practices have been complemented by nine targeted interviews of a chosen set of station actors. Observation and interviews were all concordant concerning the following statements:

Regarding collaboration between operators and support team, each operator used to walk to the support office two to five times per shift, with an average of 30% unsuccessful visits, i.e. when the support expert was absent. Missing parts were the most frequent problems reported. An average of 30% of visits were to remind the support of a pending alarm.

Regarding existing coordination system use (balancing): the system used to be updated by operators once every two days on average. As a direct comparison, AVL logs show that system's updates have been made two to four times per shifts, usually around breaks or in case of alarm.

After: Questionnaires Results

Questionnaires have been distributed after the experiment to all teams who participated to the three illustrators on the final assembly lines. In total, 41 out of the 45 questionnaires have been collected and analysed. A total of 40 multiple-choice questions were answered. The main objective was to assess user's perception of what was achieved by the new system. We analyse here the user's answers for each of the three criteria.

Overall system adequacy		
System adapted to activity:		***94%***
Improvement of the activity:		***72%***
Ease of use – Intuitivity: *(how long to use the system)*		***50%*** less than 1 day ***100%*** less than 2 days

Information consistency – Location specific interfaces		
Improved ***operational*** activity – Nomadic view		***95%***
Improved station ***management*** – Public view		***95%***
Improved ***notification*** of alarms – Public view		***85%***

Table 1 Questionnaire results – System adequacy and Information relevance (overview)

Our first concern was to evaluate AVL's overall adequacy with the station activity, not only for the station managers but for all the multidisciplinary bodies of users (**information relevance**). As shown in Table 1, despite their specific activities, *all users* highly rated the adequacy of AVL with their activity, most noting an improvement of their daily work with AVL (72%). Users also acknowledged an improvement of their specific activities in relation with the three information views delivered by AVL (*operational*, *notification*, *management*).

As shown in Table 2 and validated by empirical observations of the system in use, users validated the adequacy of the system to transmit **clear detailed information** to large panel of users simultaneously performing different tasks.

However, 29% of the users would expect the system to display more details on particular items. The on-station semi-public displays partly answer this point, but we believe that there is still room for improvement in the design solution adopted.

Information Legibility – Targeting large groups with detailed information	
Improved **vision of the station status**	***86%***
Improved **legibility of the balancing** through the multiple views (*fisheye & compressed)*	***97%***
Sufficient **level of detail** in the public views	***71%***

Table 2. Questionnaire results - Information legibility (overview)

Importance of the last factor, **information privacy**, was more difficult to evaluate. We believe that the strong adhesion of all users is a significant indicator that no concerns regarding privacy issues were raised. Indeed, on top of all questionnaires, interviews and group meetings, a total of 66 written proposals have been posted by stations actors directly on dedicated boards nearby the large public display. Those contributions to improve the project's functionalities and specifications prove the strong appropriation of the project by all users and their will to contribute to its adequacy with their actual needs.

These results appear to validate the importance of all three criteria on the system acceptance, and are confirmed by the large adhesion of end-users, from operators to management, that led to the successful industrial implementation of AVL on Airbus A380 assembly lines. The coming years will now show whether, as expected, this success yields improvements in coordination and productivity on the final assembly lines.

Conclusions

We presented the design process and methodology of AVL, a coordination system for aeronautical assembly lines' teams using a set of large public displays, semi-public displays and private interfaces to support coordination and collaboration among the multi-disciplinary distributed actors. We particularly investigated the key features to facilitate user acceptance of such a coordination system. The system design was developed through three acceptance factors: information relevance, information accessibility and privacy concerns. The results of formal evaluations as well as the industrialisation of the project suggest that the design solutions associated to these three acceptance factors have been a success.

This article describes the transposition of CSCW concepts to the production lines context and demonstrate the relevance of this field for future CSCW work. Through the AVL public and semi-public displays concepts, it highlights how public interfaces can transmit relevant information to multiple simultaneous users and how those interfaces can conciliate different levels of legibility depending on the user distance. It finally illustrates how graphical design and user-centred design process can influence the ever increasing acceptance and motivation issues.

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