The Coordinative Functions of Flight Strips: Air Traffic Control Work Revisited

Johan Berndtsson*
Linne Group, Sweden
johan.berndtsson@linnegroup.com

Maria Normark*
Royal Institute of Technology, Sweden
marian@nada.kth.se

ABSTRACT

Cooperation in time-critical and physically distributed work settings, such as air traffic control, requires extensive coordination between the involved actors. For this coordination to be efficient the controllers rely both on the comprehensive use of rules and procedures, and on artifacts supporting them in following these procedures. At the Copenhagen Air Traffic Control Center this coordination is largely carried out through the use of a flight plan database system, paper flight strips, and a closed-circuit television system. In relation to the introduction of a new and increasingly automated system in the year 2003 this paper discusses the coordinative functions served by these three, soon to be replaced, artifacts from a design perspective. Despite the skepticism expressed in previous research, our results show that a further computerization could be successful if the coordinative functions the system currently fulfills are properly preserved.

Keywords

Air traffic control, flight strips, coordination, closed-circuit television system, computerization, automation, CSCW

INTRODUCTION

Air traffic control work is a highly complex, distributed, and time-critical activity. In the Copenhagen ATC Center some 260 controllers, assistants, and supervisors are involved in the process of controlling about 1500 aircraft in Danish airspace around the clock. The time-critical aspect of air traffic control work makes it very different from e.g. accounting or design work. For example, if a designer stops working for a few minutes her sketches will 'freeze', nothing will happen, but if a controller would stop working for a few minutes the situation in the air will not freeze, but continue to change. Air traffic control work, as well as other time critical work, is thus 'paced' by this continuous change [27].

In air traffic control, aircraft are controlled from different places depending on their current location. During a departure, for example, the assistants in the apron tower, guiding the aircraft on the ground, do the initial controlling. The controllers in the tower take over and handle the aircraft while it's on the runways and during take off and landing. Approach controllers are responsible for the controlling while the aircraft is in the immediate airspace around the airport and finally, the area controllers manage the traffic while it's *en route*. Within and between these 'control rooms', controllers and assistants work together to maintain safe and cost-effective control of the flights in the Danish airspace – to ensure that the aircraft are separated at all time and that they are optimally routed to keep cost and flying time to a minimum.

To make the controlling of air traffic possible, in these time-critical and physically distributed work settings, the controllers constantly need to coordinate their work with each other. To facilitate this coordination the work is both heavily stipulated by procedures and supported by a number of artifacts. Examples of such procedures involve the division of airspace into sectors, agreements between sectors stating standard routes and flight levels (altitude) for handing over the aircraft between the different sectors etc. These procedures serve as a resource, the use of which enables the controllers to have essential information about the upcoming situation, e.g. when and where to expect a certain flight, what flight level it will have, etc. This high reliance on procedures enables the controllers to anticipate upcoming situations, and gives them time to deal with irregularities when they occur.

As mentioned above several artifacts are used to support this work. Some of these are aimed at enabling the controllers to be aware of the current situation in the sky, such as the radar; whereas others are designed to reduce the time it takes to perform recurrent tasks, such as the speed dial panel for the telephone on the controller's positions. To cope with the distributed nature of the settings described above there are also artifacts specifically designed to facilitate coordination of the controllers' respective activities in the different control rooms – artifacts interconnecting the different rooms. Examples of such artifacts used at Copenhagen ATC Center are the flight plan database, it's printouts (the flight strips), and the closed-circuit television system used to selectively display parts of controllers workplaces to other controllers.

As we show later in this paper, the way the work is currently carried out, with controllers using pens to update paper flight strips, facilitates flexibility and, together with the closed-circuit television system, coordination. There are, however, several problems with the current system. The database, for example, cannot store more than a fixed number of flight plans at a time, and at rarely occasions it gets full, and some of the flight plans

* This paper was written while both authors were affiliated with the *Center for Tele-Information, Technical University of Denmark* and the *Department of Human Work Science, Luleaa Technical University, Sweden*

cannot be stored in the system – causing problems when the aircraft arrive. Another problem with the current situation is the workload of the controllers. The handling of flight strips takes time, and in busy periods the controllers sometime feel that they are hampered by the number of tasks connected to the use of flight strips. One solution would be to split sectors even further, but the need for extra, time consuming coordination would then cancel the desired effect (p. 34, [20]). Splitting the sectors further is thus not an option. To cope with these and other problems it has been decided that a new, completely computerized and thus also 'strip-less', system, will be put to use in the year 2003.

In this paper we report on some of the findings from an ethnographically inspired field study focussing on coordination between different 'control rooms' (such as the apron tower, the tower, the approach control, and the area control) conducted at the Copenhagen ATC Center in Denmark. We describe the work of the controllers, the three coordinative artifacts mentioned above, and their use. In relation to this we discuss the diverse conclusions of other research groups regarding the use of flight strips. Furthermore, we discuss a shift in focus regarding the design of electronic flight strips from the rather limited approach of only looking at the actual data on the flight strips, to an approach where the coordinative functions are emphasized and thoroughly analyzed. Finally, we also discuss our findings regarding the coordinative functions and the affordances of the current system, and draw some conclusions regarding the coordinative functions that need to be supported in an implementation of an electronic equivalent.

RESEARCH APPROACH

The results presented in this paper are based on ethnographically inspired field studies, primarily consisting of unstructured and informal interviews, and participatory observations. About 20 interviews have been conducted with different groups involved in air traffic control work at Copenhagen ATC Center, e.g. controllers, supervisors, assistants, and technicians. These interviews were recorded on audiotape. We have also had the opportunity to talk to several Swedish *en route* controllers, from Malmoe and Stockholm.

The interviews were generally followed by participant observation sessions lasting between one and three hours each. During a majority of these observation sessions the informants were asked to continuously talk aloud about what s/he was doing during her/his actual work. We have also made longer observations and spent a total of approximately three months in the control center. During our observations we took notes, but in order to capture the details of the work, we also used video recordings. The collected data were then indexed, summarized, and discussed both within the group, and with other researchers studying control room work.

To learn more about the future of ATC technology we observed a part of a large simulation with Swedish and Danish controllers testing a version of the future ATC-system at the Eurocontrol[1] test center in Bretigny, France [5]. We also studied written materials about this new system, as well as work instructions, system manuals, technical drawings and database design specifications concerning the system currently in use.

For our definition of coordination we build on the definition of cooperative work by Schmidt[2] who states that cooperative work emerges from the limitations of individual actors that inhibit them from accomplishing certain goals individually. The actors are thus mutually interdependent in that each needs the other to accomplish the work. The necessary division of tasks between these actors also forces the actors to *coordinate* their activities. The coordination done through the herein-discussed system mainly concerns one actor's alignment of his own activities with those of another.

AIR TRAFFIC CONTROL WORK

Air traffic control work is about maintaining safe and cost-effective airborne transportation. To achieve the desired level of safety, aircraft are separated from each other throughout the whole flight. Separation of aircraft can be achieved by maintaining different altitudes, by keeping adequate longitudinal distance, or by keeping them laterally separated – giving aircraft different routes on their way to their destinations. Keeping aircraft separated might seem to be an easy task but, given the amount of traffic traveling through Danish airspace every day, the work is quite complex, and it is achieved only through the skilful and extensive use of conventions, procedures and tools, without which a lot of negotiation and conversations on coordination issues would have to be done.

As an aircraft moves from one sector to another, the responsibility for the controlling of the aircraft also moves from one controller to another. In accomplishing their work, the controllers therefore need to coordinate with each other. This means that the work done in adjacent sectors can be of mutual interest, and thus to some degree must be visible to the other controllers, enabling them to plan their own work and to efficiently hand over the traffic to the following sector controller.

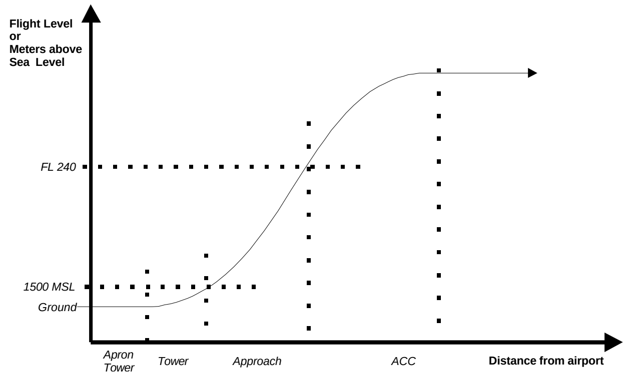

Figure 1: A departure from Copenhagen Airport showing the hand-over moments between the four controlling units: the apron tower, the tower, the approach control, and the ACC (*en route*) control.

During a departure, responsibility for the aircraft is handed over between different controllers several times (in Figure 1 this is represented by the vertical dotted lines). A hand-over is performed by the controller currently responsible telling the pilot

[1] Eurocontrol is an R&D organization working to improve air traffic management in Europe.

[2] See e.g. [26; 28].

to switch radio frequency and to contact a controller in the next sector or airspace, e.g. ‘Scandinavian niner eight seven, contact approach on one one niner decimal one’.

The Copenhagen ATC Center can be divided into four control units:

- **The apron tower** staff handles the aircraft on the ground, beyond the runways. Their main task is to communicate with the aircraft in the apron area, and also to give taxi clearances. The responsibility for the aircraft is handed over between the tower controller and the apron tower assistant before the aircraft enters or leaves the runway area.
- **The tower** controllers and assistants handle both take offs and landings on the three runways at Copenhagen airport. During a departure, they receive the aircraft from the apron tower, give the pilot clearance to take off, and hand it over to the approach control. For arriving aircraft they receive the aircraft from approach control when it is about to land, and hand it over to the apron tower as it leaves the runway.
- **The approach control** controls the aircraft around the airport. When departing from Copenhagen Airport the aircraft are handed over to the approach control from the tower immediately after take off. They are then given complementary instructions for the pre-defined departure routes, and finally handed over to the *en route* control. Approaches to Copenhagen are more complex. When aircraft enter the approach area from the adjacent *en route* sectors an approach controller accepts them, “threads them up like pearls on a string” into two single ‘landing queues’, and hands them over to the Final controller, who controls the aircraft during the very last part of their approach before handing them over to the tower.
- **The Area Control Center (ACC)** handles flights when they are *en route* in Danish airspace. Each sector is fed with aircraft from its adjacent sectors. The controller in the sector guides the aircraft through the sector by issuing orders to the pilot, and finally s/he hands them over to the following sector. While *en route* an aircraft is thus handled by many different controllers.

CONTINUOUSLY COORDINATING FLIGHT INFORMATION

As we have seen thus far, there is an extensive need for coordination – of continuously keeping actors up to date, enabling them to make appropriate decisions. In Copenhagen, the most important systems currently used for conveying, or coordinating, the controllers’ activities consist of three components: a database system, flight strips, and a closed-circuit television system. Despite its seemingly simple construction the skilful use of these artifacts efficiently handles not only pre-planned information about each flight, but also most of the changes to, and deviations from, this plan as the flight is actually executed.

As shown in Figure 2, the data regarding a flight is moved through the three artifacts mentioned above.

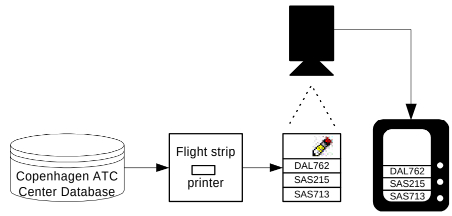

Figure 2: The system through which flight plan data is managed. Flight plan data are automatically retrieved from the Copenhagen flight plan database system, printed for, and used by, the controllers, and finally distributed through the closed-circuit television system.

All flight plans concerning Danish airspace originate in the flight plan database system. To calculate estimated times of arrival at significant waypoints the data in this database, such as flight route, aircraft type, etc. are combined with data from other sources, such as weather data etc. Well before the aircraft enters a given sector, and every time a change is made to that specific flight in the flight plan database, a flight strip for that flight is printed in the sector positions concerned with that flight. The controllers or assistants then place them in plastic holders and put them in different strip racks, where the controllers can annotate and work with them while they also become available to other controllers through the closed-circuit television system.

Managing contingencies with the flight strips

The flight strips provides the controllers with dynamic representations of each flight that will pass through their respective sectors, enabling them to plan their work before the aircraft reaches their sector. They are paper printouts containing both flight plan data from the database system e.g. planned flight level, aircraft call sign etc., as well as dynamically calculated values such as e.g. estimated time of arrival at a specific way point or inbound designator. The strips are ordered in strip racks (see Figure 3). In Copenhagen this ordering is based on navigational waypoints and the estimated times of arrival at these points. Aircraft physically located close to a significant way point in the western portion of the sector will, for example, be put on the left hand side of aircraft in the eastern portion of the sector, and the closer the aircraft are to this way point, the closer their strips are to the controller.

Figure 3: A strip rack with *en route* strips for aircraft in an *en route* sector.

The flight strips contain only more or less static data – not even the dynamically calculated data can be automatically updated on paper. To keep the flight strips up-to-date, the controllers use pens to annotate the strips in accordance with the state of affairs in their sector. Therefore, the controllers always work with a pen in their hands, ready to make notes of changes on the flight strips.

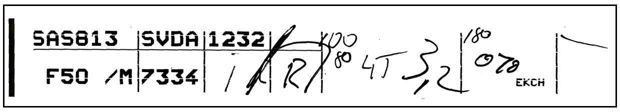

Figure 4: An annotated (updated) flight strip from the approach control.

The strips contain large amounts of information. For example, the strip above represents an approaching flight, SAS813, using transponder code 7334. The aircraft is a Fokker 50, classified as a medium sized aircraft, coming in from the SVDA way point at 12:32 PM. The handwritten ‘I’ below the estimated time of arrival indicates what weather information the pilot has been given through the automatic weather report system. The handwritten R means that the aircraft will land on the right runway, which is not standard (and thus highlighted with a box around it). The notations in the middle represents instructions given regarding changes in altitude (100, 80, 4T, 3, 2, 1) and the information handwritten to the right regards changes in heading (180, 070). Also notice the stroke to the right telling meaning that this aircraft has been given ‘no speed restrictions’ on its approach to the airport. Even though this example shows a number of different states printed or written on a strip it is also important to remember that each of these ‘variables’, plus many more, can all have a large but limited number of values, making the total number of possible combinations virtually infinite.

This standardized way of annotating and ordering the strips is essential for the coordination between the controllers because it enables them to access information about flights handled by other controllers as well, something Bentley et al. pointed out as required for efficient controlling.

> "Much of the work requires ‘at a glance’ observations of strips and flight progress boards. This can only be effective if all controllers can rapidly assimilate flight strip information and this rapid assimilation is hindered if even slight differences in strip representations are supported." [1]

As pointed out in the quotation above, there can be very few differences regarding what, where, when, and how, the individual controllers write on the strips. A heading written where flight level is supposed to be can easily be misunderstood. To reduce the risks of such mistakes there are both procedures and deeply rooted conventions to regulate these issues.

Another potential problem with the ‘at a glance’ availability mentioned above is that these data are normally limited to people within reading distance from the strip racks. In Copenhagen, however, this problem is solved through the use of a closed-circuit television system, enabling actors to follow the changing states of the aircraft in the relevant sectors. We will now continue with a discuss of this system in further detail.

The closed-circuit television system

Before the introduction of the closed-circuit television system, almost 30 years ago, all changes to air traffic that would effect other controllers had to be coordinated over the telephone. The closed-circuit television system was introduced for the purpose of reducing the need for these time consuming and obtrusive phone calls, replacing them with the ability to see the evolving situation in other parts of the airspace through different monitors. [3]

Technically the system is quite simple, and consists of cameras linked to monitors via a switchboard.

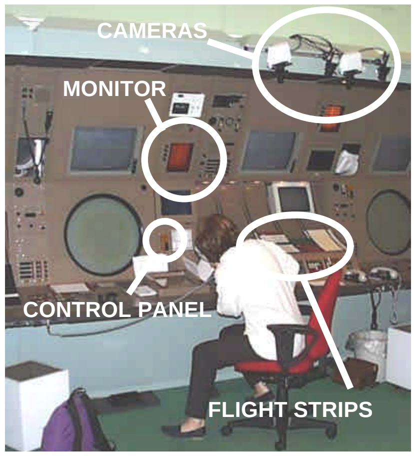

Figure 5: *En route* controller handling both the radar and the planner positions in ACC East. The cameras are aimed at flight strips for aircraft approaching Copenhagen Airport from the south.

The cameras together with two spotlights are, as shown in Figure 5, placed right above the flight strip rack, where the flight strips are placed. This control position also has a monitor were the controller can see strip racks from any other position. The picture quality of the monitors used in this system is very good, so good that even the smallest text is easily readable. There is also a control panel (consisting of a number of buttons) beside the screen, by means of which the controller can chose from which sector/control room s/he would like to see the strips. This panel is also used to choose between cameras for sectors where the number of strips that are of interest to other controllers exceeds eight, which is the limit for one camera (see Figure 6).

Different kinds of continuously open video-links, or *media spaces* as they also have been called, have been described in other research projects[4]. However, the main difference between these previous studies and the system described in this paper, Nardi et al. excepted, is mainly the focal point of the video-link itself. The vast majority of these research projects have focused on ‘talking heads’, exploring video-mediated body language as support for cooperation. The system described here, however, is focused on mediating the current state of the parts of the field of work relevant to other controllers, resulting in more efficient coordination than that reported from experiments with ‘talking heads’ [7; 13; 14; 23].

The field of view of the camera used in this closed-circuit television system is very focussed – it only shows the flight strips. The only time a movement is visible on the monitor is thus when a controller places a new strip in the rack, removes an old

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[3] A study of the introduction of this system would have been interesting, however, very few people remember how the work was carried out before, and this makes such a study practically impossible.

[4] See e.g. [2; 3; 7; 13; 21; 24].

strip, moves a strip within the rack, or annotates a strip (see Figure 6).

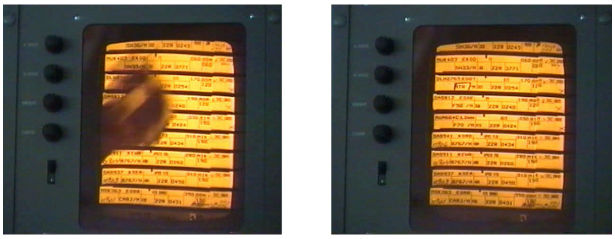

Figure 6: A closed-circuit television monitor from the approach, showing strips from the tower. Both photographs show the same monitor a few seconds apart. The sequence show a tower controller highlighting (by drawing a box around) the aircraft type of a shortly departing aircraft.

The movement of the controller's hand on the screen alerts the 'watching' controller through her or his peripheral vision that something is happening, allowing him to check the monitor when changes may have been done.

As a technological system the closed-circuit television system is quite simple: standard video cameras and monitors are connected through a video network. However, when looking beyond the physical artifacts, the use of this system proves to be quite complex. Its video cameras and monitors practically interconnect all different 'departments' working in immediate proximity of the Copenhagen approach area, Danish as well as Swedish (see Figure 7).

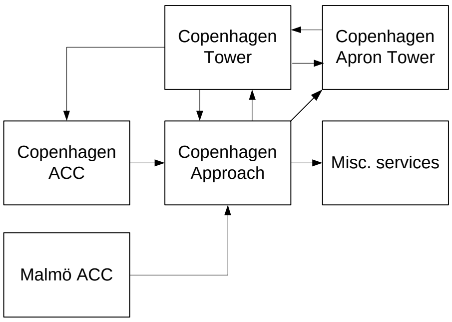

Figure 7: A schematic figure showing the default connections established through the closed-circuit television system. The arrows indicate the default camera monitor setting. Misc. services include e.g. the airport personnel, Scandinavian Airlines (SAS), and a cleaning company.

By distributing the view of the flight strips to the concerned actors, the closed-circuit television system compensates for the losses that come from the data in the database being 'out of date' as soon as a handwritten change is made to a strip. The dynamic changes to the data are thereby also taken care of in the current system, even though the changes are not automatically recorded in the database.

In this system, the pre-planned data is managed in the database. However, changes to the flight plan are mainly managed through annotations of the flight strips. The system can thus be described as having two parts, one static and one dynamic. The problem with this configuration is that the information in the database is not automatically updated as notations are made on the strips, but rather decays as the plans for the flight continuously evolve. Some changes, however, are made directly in the database, causing a new strip to be printed in the concerned sectors, but such changes are rarely made, mostly due to the updating process being too time-consuming. Having static, or manually updated, representations of the state of affairs in time-critical and physically distributed work settings is problematic since the changes can only be propagated with difficulties.

THE USEFULNESS OF FLIGHT STRIPS

What makes the flight strips so useful in air traffic control that they are still being used as one of the most important tools, in spite of their shortcomings? In this discussion we summarize some of the quite divergent results from previous studies of the use of flight strips.

In their reports and papers, the Lancaster University CSCW group presents the flight strips as being of central importance in air traffic control work [10; 20][5]. They also point out that the physical properties of the strips, such as their tangibility and the ability to write directly on them, play a major part in air traffic control work.

> "For, in terms of the kind of features we have identified as involved in 'working the strips' and the place they occupy in the social organisation of controlling work, many of these are related to, if not precisely dependent upon, the physical character of the strips themselves." (p. 21 [10])

Making notes, writing symbols on strips, positioning them slightly out of place to accentuate possible conflicts, and showing them to each other are all actions that are crucial in European air traffic control work settings today, actions that are supported by physical strips (p. 29-31, [10]). These findings are supported by Hopkin, who in several papers has pointed out that the informational richness and flexible character of paper flight strips make them highly useful in air traffic control [15; 16]. He summarizes the use of flight strips in air traffic control in his 1995 book:

> "The paper flight progress strips exemplifies some of the attributes of air traffic control itself. It is incomprehensible to the layman for it contains no obvious information about what it is for, or how it is used. Initial impressions of it can be deceptively simple. It does not look complex, but seems to contain quite a small amount of information, all of which could be quantified and presented electronically. In fact, the paper flight progress strips has evolved into a complex and subtle tool." (p. 25, [16])

But while Hopkin's conclusions are very similar to those of the Lancaster group, other researchers have come to very different conclusions. A group at the University of Oklahoma, USA, has been doing extensive research, using a different research approach on the use of paper flight strips, and in several papers claims that they in fact are not very useful at all. In a 1995 paper they state that the controllers "feel that the only tool necessary for air traffic control is the radar, and that any time spent away from the radar is time spent away from their primary task" (p. 2 [4]). In another paper they write that:

> "The pattern of findings implies that board management was affected by the complexity of the of the scenario. In the more complex scenarios, the controller was forced to find time to keep the board configured and updated, and he or she did this in concentrated time segments. During these times, controllers may

5 See [8; 9; 11; 12; 29] for more on this subject, but also [1; 17-19; 25] for related papers focusing on the development of ATC systems where Sociologists and Computer Scientists work together.

feel that they have 'been taken away' from the plan-view display and the traffic situation." (pp. 341-342, [30])

Their conclusions are almost contradictory to what has been presented by both the Lancaster group and Hopkin. However, interestingly we have found support for both the Oklahoma group's claims, regarding the *opinions* of the controllers, and the Lancaster group regarding the multiplicity of ways in which the strips are being used. Regarding the controllers' opinions a substantial number of controllers named the radar as their most important tool, and several air traffic controllers have stated in interviews that the current way of working with paper flight strips takes too much time:

> "In some sectors we have up to three strips for the same flight, there simply isn't enough time to handle them all."
>
> (*En route* controller in Copenhagen)

However, as concluded by both the Lancaster group and Hopkin, paper flight strips are both complex and extremely useful. Our observations show that the strips are used in a way similar to that described by the Lancaster group [10]. The flight strips are annotated, pointed at, moved, ordered, tilted, both to support the controller's own memory and to make information available to other controllers. But even so, this does not necessarily preclude a transition to a more computerized system.

Steadily increasing amounts of traffic in the airspace[6] is slowly forcing air traffic controllers to adopt an increased amount of automation, which has led to several attempts to automate the handling of strips in the past, most of them unsuccessful. Hopkin concludes that these failures are a result of an emphasis on the flight strip's attributes instead of on their functions, and furthermore that "the strips contain no functional information about their purposes, their uses, or the meaning of their contents" (p. 62, [15]). Thus, just transferring the attributes of flight strips onto computerized system is no guarantee of maintaining the many functions that the paper flight strips fulfil. Hopkin continues:

> "In conclusion, whatever form electronic flight strips take, it is essential to define beforehand all the functions of paper flight strips, in order to discard any unneeded functions deliberately and inadvertently, to confirm that familiar essential functions can still be fulfilled electronically, and to appreciate the functional and cognitive complexity of paper flight strips." (p. 64, [15])

While we do agree with the main point of Hopkin's statement, that all[7] *functions* of the flight strips must be defined, we would emphasize the importance of the coordinative functions served by the flight strips, especially when used in combination with the closed-circuit television system. These functions, however, often tend to be forgotten, or are too much taken for granted to be noticed. In a discussion with a controller about the flight strips and the closed-circuit television system, she (as most of the controllers) stated that they would do fine without strips, but that they could never do without the closed-circuit television system! Of course the system would be useless without the strips, with blank monitors, but the point is that the way the system works today fulfills a coordinative function that has to be retained, a function so embedded in the work that she could not quite put her finger on it.

Another aspect is that, without diminishing the importance of flexibility in use and the functions fulfilled by the paper flight strips, there are, as mentioned briefly earlier, shortcomings with the current system. During one of our visits we observed the following event:

> Two aircraft are approaching the airport from the same way point. The agreed way to hand over aircraft from adjacent sectors into the approach area is to keep them longitudinally separated from each other, queued with a minimal distance of five miles. However, on this occasion the controller in the adjacent sector decides, to send both aircraft in with altitude separation and no longitudinal separation, and marks his strips accordingly. This is, however, usually telephone coordinated with the receiving controller. The approach controller does not notice the sending controller's notes regarding this deviation on the closed-circuit television monitor, so the controller orders one of the aircraft to descend – causing the one aircraft to descend towards the other. A few seconds later, when the controller sees the two aircraft on his radar, right on top of each other[8], it is time to act quickly to maintain safety distance.

Even though there was never any real danger, the two aircraft were never really close to each other, this incident underscores the need for a system where this kind of decision made by the controller in the adjacent sector, is either directly negotiated with the receiving controller or, at least in some way, highlighted on her or his display. The unobtrusive[9] character of this system, in many situations beneficial by allowing the controllers to choose when to check it, can also be a hazard to the safety. The usefulness of the paper flight strips, even together with the closed-circuit television system, is thus greatly limited since there are highly desirable features, such as conflict alert systems, that cannot be implemented without developing systems where the plans for the flights are integrated with their actual execution.

However, substantial improvements within several areas of air traffic control should now make it possible to move away from the use of flight strips. *First*, more efficient procedures, such as better-defined standard routes for arrivals and departures reduce the need for negotiation between the involved controllers[10]. *Second*, more efficient work arrangements have reduced the need for coordination between the involved actors. Through these changes both the number of phone calls, and the need for constantly monitoring different sources of information, has been reduced considerably. *Third*, the redesign of the airspace,

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[6] Air traffic in European airspace increased by six percent in 1997, and is predicted to double by 2015 [6].

[7] Or rather that all of the *critical* functions have to be defined, and that there has to be enough 'room' to solve unforeseen problems outside the system, when they occur – because they will.

[8] The labels on the radar screens used in the Copenhagen Air Traffic Control Center can overlap each other, making both of them practically unreadable until you manage to move one of them, which takes at least five seconds. Five seconds can be a very long time for a controller.

[9] Schmidt has discussed the degree of obtrusiveness as a feature of any 'mode of interaction', see e.g. [26].

[10] See e.g. studies by Lockhart and Pyburn [22].

regarding both the division into sectors and the structure of the navigational waypoints not only reduces the distance and flying time for the aircraft, but can also reduce the number of hand-overs per flight, thereby reducing the number of controllers involved in the controlling process. *Fourth*, the continual development of more efficient and better suited artifacts to support the controllers in their work, consisting of everything from speed-dial panels for phone calls to advanced systems for controlling the number of aircraft in the approach area, provide the controllers with more time to handle coordination when the need arises.

For the new system in Copenhagen another, more thoroughly studied, approach has been chosen. Copenhagen ATC Center in collaboration with Eurocontrol are currently implementing a strip-less multi-function radar display system that will be put into use in the year 2003. In terms of this paper, however, the approach chosen is of little importance.

Regardless of what the system might look like in the future, there are several essential functions that must be kept intact. The *paper* flight strips are thus not in any way irreplaceable as a tool for air traffic controllers *as long as these essential functions are provided in the new system*. We will now discuss these functions further.

ESSENTIAL COORDINATIVE FUNCTIONS

Then, which coordinative functions fulfilled by the current system are so important that they have to be kept intact in the design of a successor?

As a very general claim one could describe the flight strips and the closed-circuit television system as an ‘awareness mediator’. The Lancaster group has emphasized the importance of ‘at a glance’ availability of important information for the controllers in a sector. With the closed-circuit television system this availability stretches to include controllers located in other locations. The system thus makes it easier for the controllers to plan and prepare their work since they can follow the flow of flights on the monitor and thus also the changing state of the skies. However, these vague statements about awareness are not very useful when discussing coordination and the design of coordinative artifacts such as a computerized equivalent of the current paper based system. They can only lead to equally vague conclusions that will not say anything specific about the actual coordination that occurs among the involved actors.

To more precisely analyze these issues we will briefly describe some of the coordinative functions we found in our studies.

Coordinative functions: Departure

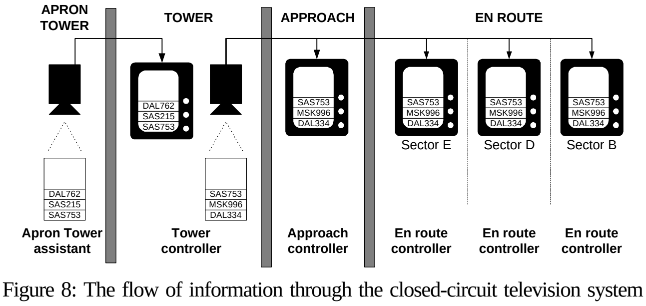

Figure 8: The flow of information through the closed-circuit television system during a departure from Copenhagen Airport.

In Figure 8, a flight strip representing the departing aircraft is first printed in the apron tower. An apron tower assistant places the flight strip in the strip rack, and thereby the strip is fully visible to the controllers in the tower. Before the aircraft takes off, however, a strip is also printed in the tower, and placed in a rack by a tower controller. This strip is now visible on monitors in both the approach and in the *en route* control.

The first coordinative function served by this system takes place between the apron tower and the tower. Before the aircraft pulls out from the gate the apron tower assistants place the strips for the departing aircraft in their strip rack in accordance with the filed flight plans. These strips are visible through the closed-circuit television system on a monitor in the tower. By checking this monitor, the tower controllers not only get information about the order of the aircraft, but should the weather conditions change rapidly they can also make decisions regarding when it would be appropriate to change runways. If there are many aircraft on and around the runways, a traffic jam can thus be avoided by choosing an appropriate moment for the change.

Between the tower and the approach control the relation is more complex. The departure controller in the tower has her or his own strips placed in the strip rack, which is visible in the approach. In the approach control, however, there are no strips for departing aircraft. Here the controllers have to rely on, and use, the strips from the tower, presented on the closed-circuit television monitor. Thus, the approach controllers handling departures regularly look for several things on the strips, e.g. route and aircraft type, to make sure that no faster aircraft will catch up with a slower one having even partially overlapping departure routes.

> “On this strip (points at a strip on the closed-circuit television monitor) I can see that I don’t have to do anything to this aircraft. The tower controller has ordered the first aircraft, which is a propeller, to stay at 4.000 feet, and turned him slightly to the right, so that the following aircraft, a jet, which is much faster than the propeller, can climb and depart without any risk of conflict between the two.”
>
> (Approach/tower controller in Copenhagen)

The approach controllers also look for the aircraft call sign, to prepare themselves for who’s calling next and to plan the different departures. They look for printed messages such as e.g. SEFITO (Simulated Engine Failure In Take Off), telling them about special conditions for that specific flight. Also, perhaps most important, they look for all handwritten signs, marks, messages etc. In the example above, where the approach controller was looking for the route and aircraft type, there were handwritten signs telling the approach controller what the tower controller had done.

There are also more explicit forms of communication taking place through this system. One example is the strips designed by the tower controllers themselves, containing messages such as ‘Vehicle on runway’, which in this case tells the approach controller that no aircraft can land or take off from that runway at the moment. The kinds of direct messages that are displayed through the closed-circuit television system mostly seem to contain information that the watching controllers do not need to know to do their job, but rather information to keep these controllers from wondering what's going on. Apart from the obvious, that it may be considered nice to inform dependent colleagues of your current work situation, the messages can also be conceived of as preemptive, providing other controllers with information only to avoid being interrupted by phone calls with questions.

The *en route* controllers also watch the tower strips. This use however is more related to long-term planning since the strips displayed informs these controllers about the number of aircraft heading their way within the next five to fifteen minutes.

Coordinative functions: Approach

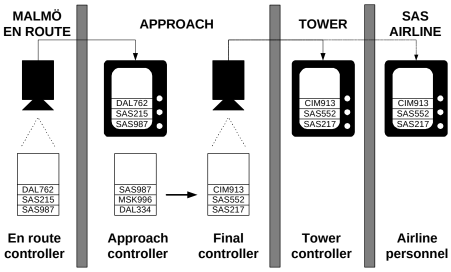

Figure 9: The flow of information through the closed-circuit television system during an approach to Copenhagen Airport.

As shown in Figure 9 the approach starts with a Swedish controller in the Malmoe ATC Center placing a strip in the rack for flights entering the Copenhagen approach area. The strip is thereby visible on the approach controller's monitor (the middle of the figure). As the approach controller then directs the aircraft, merging it with other arriving aircraft, he continuously makes notes on his strip representing the same flight. When the aircraft is lined up he then physically hand the strip and thereby also the aircraft over to the Final controller. She or he places the strip in a rack under a camera and then guides the aircraft during the very last part of its approach, all the time making notes on the strips reflecting her or his directions. Once placed under the camera, the strip becomes visible to the tower controller handling arriving aircraft, but also to other interested parties such as the SAS personnel handling the gates.

There are several important coordinative functions served as the activities evolve. Before the closed-circuit television system was implemented, e.g., every hand-over between Malmoe and Copenhagen approach had to be coordinated through telephone, but with the closed-circuit television system the controllers in Copenhagen just look at the screen to know which aircraft are approaching, and in what order. The usefulness of this system increased even further a few years ago when a Sequencing and Metering system was introduced. The Sequencing and Metering system was developed to handle both longitudinal separation of aircraft, and to suggest a landing sequence for aircraft approaching an airport, and in this case the system automatically provides Malmoe with timeslots when Copenhagen can accept aircraft from each of the specific entry points. The use of the flight strips and the closed-circuit television system, together with the Sequencing and Metering system, allows Malmoe to send in any aircraft, not just the one decided by the Copenhagen approach. As long as they use the assigned timeslots, and the order is clearly visible on the closed-circuit television monitor in the approach control, any sequence can be accepted.

Between the approach control and the tower the closed-circuit television system enables the tower controllers to see the actual landing sequence of the approaching aircraft. Even though they already have a system (the Sequencing and Metering system) that is supposed to provide them with the actual landing sequence for approaching aircraft, they have to use the strips and the closed-circuit television system since the predictions made by this system are seldom accurate. Another example of coordination between the approach and the tower through the closed-circuit television system is the hand-over of aircraft from the approach controller to the tower controller. When the approach controller instructs the pilot of an aircraft to contact the tower, the approach controller also makes a stroke with her or his pen on the strip[11], just to remember that the aircraft has been handed over to the tower. However, this stroke also allows controllers in the tower to know that the aircraft is now on her or his frequency. Actually, this very same stroke is also useful in other ways. It is also used by e.g. SAS (Scandinavian Airlines), but in this case the use results in the personnel being able to man the gate in time for the arrival of the aircraft.

Similar to the explicit communication described in the departure, the approach controllers use the system for direct messages, such as 'Long break', telling the tower controllers that there won't be any traffic for a while, thereby avoiding disturbing phone calls.

The coordinative functions illustrated by these cases are essential to achieve effective air traffic control, and in the case of the airline monitor, also effective air traffic services. Any system designed for use at the Copenhagen ATC Center should therefore take these into account.

DISCUSSION

We summarize the coordinative functions of the current system in four points below, each ending with a recommendation for the design of a replacement system.

First, what is striking from this study is how well the use of the database, the flight strips, and the closed-circuit television system supports the controllers in coordinating their activities with each other. Coordination in air traffic control to a large extent is done through the controllers' continuous alignment of their own activities with those of the controllers working in the adjacent sectors. As shown above, the closed-circuit television system is mainly used to coordinate activities downstream, to make information available to the controllers who are next to being in charge of the featured traffic, thereby supporting their planning and alignment to previous events. *A new system therefore has to support the controllers need to align their works to what others have done – distributing appropriate information regarding the changing state of the colleagues' work to the right recipients* . Obviously, what is appropriate information varies among the different types of controllers.

[11] See the strong diagonal stroke on the strip in Figure 4.

Second, a majority of the coordinative functions fulfilled by this system are embedded in the existing work; they are done without imposing any extra tasks on the controllers. The symbols written on the strips are generally written for the writing controller's own use, as a memory aid, but also for the controller on the following shift. One example of this is the stroke of a pen discussed earlier. In this respect the use of a closed-circuit television system could be seen as an added value derived from an already existing work practice, or as one of the controllers put it:

> "It (the closed-circuit television system) is very convenient since I make my notes on the strips anyway… if someone else can use them, that's great!"
>
> (Interview with *en route* controller from Malmoe, Sweden)

In order for any computerized equivalent to this system to succeed it therefore must support the same kind of effortless visualization of the current state of her or his work on the behalf of the 'sender'.

Third, beside this effortless coordination the system also allow explicit messages, such as e.g. 'Vehicles on runway', specifically aimed at the presumed viewers of that channel. These specific messages can be an important tool in reducing the number of obtrusive phone calls that otherwise would be placed to the 'sending' controller. *This kind of intentional and specifically aimed message regarding coordination issues also needs to be supported.*

Fourth, the coordinative functions provided by the closed-circuit television system are all unobtrusive, allowing the controllers to attend to what they consider to be of highest importance at the moment. However, as described in the section on the usefulness of the flight strips, unobtrusiveness has a price. It generally works well in non-critical situations, as well as for long term planning, but for other situations more obtrusive techniques have to be used. *In a new system both the 'sending' controller as well as the system, in the case of conflict alerts, must therefore be able to specify the degree of obtrusiveness of their messages.*

CONCLUSIONS

In this paper we have described the current work situation for the controllers in Copenhagen ATC Center, some of the coordinative artifacts they use, and which functions these artifacts fulfil. Previous research has emphasized the use of the paper flight strips, and also the affordances that come from their materiality. Although there is no question about the usefulness of paper flight strips, detailed descriptions of the functions that these flight strips supply, together with the continuously evolving procedures around air traffic control work, should make a move towards a more computerized system, containing, e.g., conflict alert functions possible. The flight strips in themselves are not irreplaceable as coordinative tools in air traffic control work; instead, the importance lies in understanding exactly what essential functions they fulfil, and which of their characteristics to reinforce in the design of a worthy successor.

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