Coordination and Cooperation in Air Traffic Control (ATC)

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A number of new technologies and initiatives have been developed in the air traffic control environment that are designed to meet the challenge of managing the significant projected growth in air traffic by the year 2025. These technologies are typically based on iterations of the current formally specified system with little consideration of the system as enacted by people. In Australia, the air traffic control (ATC) systems are designed to enable large volumes of aircraft to be controlled with minimal need for interaction between the controllers. Controllers are able to initiate and execute pre-defined plans with a minimal level of collaboration (called coordination) with other controllers. However, there is some evidence that controllers engage in more detailed forms of collaboration (called cooperation) with other controllers to manage anomalies and make a somewhat efficient system more effective. At the level of individual ATC interactions cooperative activities are rarely articulated in Australian ATC procedures, training programs or formal checking systems, nor are they typically considered by new developments that are designed to enhance system capacity. This study examines the patterns of coordination and cooperation used by air traffic controllers in an Australian ATC facility on normal everyday workdays. The analysis of these observations found that almost a third of interactions with other controllers could be classified as cooperative, with about two thirds of the interactions being coordinative. This shows that controllers are engaging in collaborative activities beyond what would be expected by the system as designed. This suggests that more focus needs to be placed on the way that controllers are actively managing safety in the context of Australian ATC procedures, training programs, and checking systems. In addition, this research has implications for the development of new systems designed to enhance capacity.

Practitioner Summary: This paper describes a research study that offers insight into subtle collaborative activities that are occurring outside of the formal design of the ATC system, but nevertheless contribute to making that system efficient and resilient. The ATC system is based on standardised routes that enable large volumes of aircraft to be controlled. In this system, there is only a basic level of collaboration required between controllers (which is known as coordination). To be able to handle anomalies and to make a somewhat efficient system more effective controllers engage in more sophisticated forms of collaboration (called cooperation). However, cooperation is rarely formally articulated in Australian ATC procedures, training programs or formal checking systems, nor is it typically considered by new developments that are designed to enhance system capacity. Understanding and elaborating these more sophisticated collaborative practices offers the potential to improve training outcomes, safety performance and better focus automation and systemisation initiatives.

Keywords: Air Traffic Control, Collaboration, Activity Theory, Plans, Safety

1. Introduction

ATC globally is confronted by the challenge of increasing air traffic movements, predicted to double in the period 2007 to 2025 (International Civil Aviation Authority, 2010). This will bring with it a consequential increase in operational complexity and test the system’s capacity to sustain high levels of safety performance. Two strategies currently being deployed to address this challenge in the ATC context are increasing standardisation or systemisation of air traffic management (Boeing, n.d.) and increasing automation of work processes. These strategies have the potential to significantly increase capacity,
however implementation needs to be done with a detailed understanding of work practices in the ATC environment so that important aspects that allow the system to be resilient are not lost. (Bentley, Hughes, Randall, Rodden, Sawyer, Shapiro, et al., 1992; Patterson, Woods, Cook & Render, 2007).

Morel, Amalberti and Chauvin (2008) have argued that safety performance consists of two key components: constraints-based safety and managed safety or resilience. Constraints-based safety typically relies on the application of prohibitions or protections, either physical or procedural that limit the scope of action within the system. Managed safety or resilience is a capability that is derived from the system’s ability to recognise and respond to perturbations that typically fall outside the scope of the normatively based safety constraints (Morel, et al., 2008).

In Australia, the ATC system contains standardised routes that enable large volumes of aircraft to be controlled with minimal need for interaction between the controllers. In the formally specified system, controllers initiate and execute predefined plans within their airspace volume to ensure adequate separation between aircraft. In Morel et al.’s terms, this system manages safety through constraints. The system as designed is the basis for the operating procedures, training programs, and formal checking programs. This is also the system that is used as the reference point for the development of new procedures and technologies. However, focusing on the formally specified system neglects the second of Morel et al.’s components of safety, managed safety or resilience.

While the system as designed does not formally require much interaction between controllers, there is some evidence that controllers do collaborate with each other to manage anomalies and make a somewhat efficient system more effective (Bentley et al., 1992). For example, a controller may need to interact with another controller to coordinate an ad-hoc flight transitioning through their airspace. These kinds of interactions can be characterised as managing safety or enabling resilience and there is typically little recognition of this in the formal instantiation of the system. However, we contest that understanding the nature of this collaboration is central to effective system management and must underpin future solutions that are developed to enable ATC to deal with increased capacity demands while maintaining or indeed improving overall safety performance.

Collaboration can be defined as a social process by which people exchange and synthesize information and perspectives to better understand and solve complex problems (Rawlings, 2000; Gardner, 2005). From this shared understanding, individuals are able to interact to create or modify plans for action that are more robust than could be achieved by any individual alone. Following Bardram (1998) and Miguel (2006) we conceptualise collaboration as a three level hierarchical structure consisting of three discrete types of work: Coordination, cooperation and co-construction. Work is seen as dynamically stable, moving up and down the hierarchy in response to problems or opportunities and back down the hierarchy once changes are agreed on. This movement in the hierarchy can be explained in the context of: Actions, plans and goals (Figure 1). Collaborative work, in the time constrained ATC environment, is facilitated and coordinated pre-emptively through the use of plans and the planning process is a vehicle for the distribution of cognition. Plans as an outcome, and their related enabling processes and activities provide a context for collaborative activity. They
also provide a means of propagating or sharing information as an enabling and supportive representational state throughout the system.

![Diagram showing Co-construction (Goals), Cooperation (Plans), and Coordination (Actions)](image)

Figure 1. Type of collaborative work (coordination, cooperation and co-construction).

If controllers use constraint-based safety and work within the system as designed, then we would expect all of the interactions to be coordination, which is where plans are being carried out. If however, controllers are managing safety, then they will engage in cooperation, where plans are modified. To investigate the importance of managed safety in ATC we examined the relative frequencies of coordinative and cooperative work used by controllers in an Australian ATC facility during normal everyday workdays.

2. Method

2.1 Participants

Eight participants were observed. These participants were all experienced controllers with a minimum of 25 years ATC experience and at least 10 years’ experience in their current role. Participants who were observed were randomly selected for observations from a pool of volunteers.

2.2 Design and Procedure

Ten observations of the eight controllers were conducted over a four week period in a Terminal Control Unit (TCU) serving an Australian capital city. In this unit there are 3 discrete radar executive positions: P2, P3 and P4. These positions are supported by a Flow Planner position who is responsible for providing planning support to radar executive positions and for sequencing arriving traffic at the primary airport. Figure 2 shows the lateral boundaries of the three different volumes in the terminal airspace (shown from above) in which this study was conducted. While Figure 2 represents these volumes in two dimensions they are in reality three dimensional. A single controller normally controls aircraft within a volume communicating with and handing each aircraft to adjacent controllers as it passes from one volume to another. Observations were conducted by a single researcher from the perspective of an individual controller within the team.
researcher was both a qualified controller (previously certified to work in the unit where the study was conducted) and a human factors specialist. Only interactions between controllers were considered in this study and only routine operations were observed. Detailed records in the form of activity logs of controller verbal interactions were made using time stamped written notes. A narrative summary was written up immediately after each observation and reviewed with participants to correct any inaccuracies.

Figure 2. Lateral boundaries of the airspace volumes and aerodrome locations shown from above (runways are not to scale)

2.3 Analysis
The data was coded according to whether or not interactions in each exchange between controllers were coordinative or cooperative. Coordination was coded when the standard plan for the movement of an aircraft was enacted. If there was subsequent modification to a previously selected plan it was coded as cooperation. Modification to the goals of work was to have been coded as co-construction, but no elements of this type were found in the data. The validity and reliability of the coding was established by having 20% of the observational records re-coded by a research assistant. This inter coder reliability check resulted in a Kappa of .8. The results of this analysis were presented to a selection of research participants seeking their feedback to validate the accuracy of observations and reasonableness of the conclusions drawn.
3 Results and Discussion

Analysis of the data (Figure 3) revealed that there were 186 instances of coordination, which is where the controller enacts the system as designed. An example of coordinative interaction can be found in Figure 4 (Lines 106-107). There were 74 instances of cooperation, where the controllers are modifying plans for the aircraft. An example of a cooperative interaction can be found in Figure 4 (Lines 100-102). This provides some support for the premise that the work of ATC is subtly collaborative and is consistent with Bardram (1998) and Miguel's (2006) exposition on the dynamics of work in the activity theory tradition. In contrast to the formally specified system, which is focused on constraint-based safety, we have been able to identify in this study that there is a significant amount of interactions between controllers focused on actively managing safety.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative interactions</td>
<td>74 (28%)</td>
</tr>
<tr>
<td>Coordinative interactions</td>
<td>186 (72%)</td>
</tr>
<tr>
<td>Total interactions</td>
<td>260</td>
</tr>
</tbody>
</table>

Figure 3. Coded collaborative elements by frequency of occurrence.

While it was possible to distinguish interactions that are coordinative and interactions that are cooperative, the stream of communication between two controllers often showed dynamic shifts from coordinative to cooperative work and back again in a single exchange as controllers deal with multiple aircraft at the same time. As an example, Figure 4 shows exchanges that are either completely coordinative or cooperative (lines 106-107 and 108-113) and exchanges that show switching between coordination and cooperation (lines 103-105). This shows that there is not a neat separation between work that is based on constraint-based safety and work that is designed to cooperatively manage safety in a complex environment like ATC. In this environment, both types of work are carried on more or less together. ATC work then can be characterised as dynamically elastic, shifting from coordinative to cooperative activity, in response to opportunities for enhancing goal attainment. This is consistent with van Fenema’s (2005) conceptualisation of ‘Collaborative Elasticity’ as a capability of high reliability organisations that ultimately enables adaptability.

It should be noted that in such situations it may not be easy for those involved in the work to remain mindful of the type of activity being undertaken at any given time, and as such there is the potential to fail to be explicit and infer or imply shared understanding. In this context, good performance occurs when inferred or implied parts of a modified plan are made explicit.
<table>
<thead>
<tr>
<th>Line No.</th>
<th>Time</th>
<th>From</th>
<th>To</th>
<th>Summary of verbal communications (paraphrased)</th>
<th>Type of Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0007</td>
<td>P1</td>
<td>P2</td>
<td>ACFT 3 will have to wait a bit so suggest the Runway XX VOR holding pattern</td>
<td>Cooperation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td>103</td>
<td>0007</td>
<td>P4</td>
<td>P2</td>
<td>ACFT 2 concur A040 and</td>
<td>Cooperation</td>
</tr>
<tr>
<td>104</td>
<td></td>
<td>P2</td>
<td>P4</td>
<td>ACFT 3 south on heading A030?</td>
<td>Cooperation</td>
</tr>
<tr>
<td>105</td>
<td></td>
<td>P2</td>
<td>P4</td>
<td>ACFT 2 A040, concur ACFT 3 A030</td>
<td>Cooperation</td>
</tr>
<tr>
<td>106</td>
<td>0009</td>
<td>P2</td>
<td>P4</td>
<td>Can I have lower for ACFT 2?</td>
<td>Coordination</td>
</tr>
<tr>
<td>107</td>
<td></td>
<td>P4</td>
<td>P2</td>
<td>No restrictions ACFT 2</td>
<td>Coordination</td>
</tr>
<tr>
<td>108</td>
<td>0010</td>
<td>P2</td>
<td>P4</td>
<td>(Heard P4 telling XX (external unit) Military Restricted area finished), copied finished Mil Restricted area</td>
<td>Cooperation</td>
</tr>
<tr>
<td>109</td>
<td></td>
<td>P2</td>
<td>P4</td>
<td>ACFT 1 direct NPOSN stay with me</td>
<td>Cooperation</td>
</tr>
<tr>
<td>110</td>
<td></td>
<td>P4</td>
<td>P2</td>
<td>Concur ACFT 1</td>
<td>Cooperation</td>
</tr>
<tr>
<td>111</td>
<td></td>
<td>P4</td>
<td>P2</td>
<td>ACFT 4 NDB procedure turn</td>
<td>Cooperation</td>
</tr>
<tr>
<td>112</td>
<td></td>
<td>P4</td>
<td>P2</td>
<td>No restrictions ACFT 4, check Position 3 reference ACFT 5 (20 NE for XXILS)</td>
<td>Cooperation</td>
</tr>
<tr>
<td>113</td>
<td></td>
<td>P2</td>
<td>P4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Examples of cooperation and coordination in exchanges between controllers

While the study has identified that controllers do appear to be using cooperation (where controllers are modifying plans) the method used does have some limitations that should be considered. For example, data was collected by a single researcher who may have been subject to observer bias which could have subconsciously influenced their observations. This may have been particularly problematic in this study given that the researcher was also an experienced controller. To the extent possible this potential source of bias was eliminated by recording controller interactions as accurately as possible and having the observational data validated by the subjects. Another potential issue was behavioural modification by participants due to the fact they were being observed. This was addressed by not interacting with participants during observations and not assessing the quality of their work. A further limitation is that data from a relatively small number of observations was used in the analysis, and while this demonstrates that cooperation is occurring, it may be that this is unique to these participants rather than something that happens more widely in air traffic control. There is a need then to validate these findings with further analyses.

Despite these limitations a rich contextual data set has been collected that has and will allow detailed analysis of collaborative practices between controllers during normal operations. This suggests the need to develop a framework of collaboration in ATC that is grounded in the literature but defines both the system as designed (the constraint-based system) and the system as used (the managed safety system). More
broadly, this research highlights that more attention needs to be paid to the subtle collaborative activities (such as cooperation) that controllers use to actively manage safety in the operational procedures, training programs and checking systems. Finally, this research has implications for the development of new systems designed to enhance ATC capacity. Automated systems introduced in the ATC environment have progressively reduced the need for team interactions (Wickens, Mavor & McGee, 1997). This has had the unintended consequence of reducing the system’s capacity for teamwork and obscuring the importance of sustaining team situation awareness. Future work on automated ATC systems should consider how further reduction of team interactions might adversely impact the system’s capacity to be adaptive and responsive (Amalberti, 2001). The work presented here suggests that this teamwork can be subtle, implicit and informal but nevertheless critical to successful system operation. People, with all of their inherent idiosyncrasies, are paradoxically not only part of the safety management problem but also an essential part of the solution in the ultra-safe system.

Disclaimer
The views expressed in this paper are those of the authors only and are not intended to imply endorsement or consideration by the host organisation who enabled the research activity.

References