

# Improving the Management of Controllers' Interruptions through the Working Awareness Interruption Tool: **WAIT**

by

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A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Systems Design Engineering

Waterloo, Ontario, Canada, 2014

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## **Author's Declarations**

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

## Statement of Contributions

### Conference Papers

Alqahtani, M., Histon, J. M., & Scott, S. D. (2013). Designing an interruption management experiment: Evaluating the Working Awareness Interruption Tool. *Canadian Aeronautics and Space Institute (CASI) Annual General Meeting*. Toronto, ON.

Alqahtani, M., & Histon, J. M. (2012). Improving the Management of Interruption through the Working Awareness Interruption Tool: WAIT. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 56, pp. 393–397.

## Abstract

Interruptions in time-critical, dynamic, and collaborative environments, such as air traffic control (ATC), can provide valuable, task-relevant information. However, they also negatively impact task performance by distracting the operator from on-going tasks and consuming attention resources.

This thesis develops and assesses a tool to assist radar air traffic controllers in managing interruptions. Field observations and interviews with air traffic controllers were utilized to develop an understanding of how interruptions occur in real ATC environments, and to identify where opportunities exist to use technology to support the interruption management process. It was identified that operators in these environments could better manage the effects of interruptions if there were indications to one operator of the availability of a collaborator and the urgency of an interruption from a collaborator. Present communication systems do not facilitate the awareness of these functionalities.

An initial prototype for providing these functionalities in operational ATC displays was designed. Feedback on the prototypes was solicited through Participatory Design (PD) sessions with air traffic controllers. Based on the refinement of these prototypes, the Working Awareness Interruption Tool (WAIT) was developed to support more efficient and appropriate interruption timing in the context of complex, real-time, distributed, human operator interactions. Variations of the tool demonstrated several ways of showing the availability of the controller to be interrupted (either through manual settings or automatic detection) as well as incorporating a means of conveying the urgency level of the interruption.

In order to examine the utility of the tool and to assess the importance and validity of its features, an experiment was conducted in a laboratory-based setting. The results of the experiment show the potential of this tool in an environment representative of air traffic control tasks and communication. Although the sample size was limited, the WAIT facilitated improved performance on both objective measures and self-reported measures, and reduced the distraction effects of interruptions from other operators. These improvements occurred without affecting perceptions of the effectiveness of communications. Questionnaire and interview results showed that participants appear to prefer an automated setting of availability to be shown to other collaborators.

Identifying two examples of key features supporting interruption management (communicating availability and urgency) in air traffic control is one of the key contributions of this work. The work also makes a contribution by demonstrating that providing a tool incorporating these features can improve performance in an environment representative of ATC, albeit with naïve participants. Finally, the research makes a contribution by presenting the challenges associated with evaluating interruption management tools that require collaboration between operators in a system.

## Acknowledgements

First and foremost, all Praise is due to Allah (God), the most beneficent, the most merciful.

I thank Him for helping me through my master's degree and for blessing me with the successful completion of this thesis.

Prophet Muhammad (Peace be upon him) said "Whoever does not thank the people is not thankful to Allah." So this is an opportunity for me to thank everyone whom I have learnt from during this journey and whom had a direct or indirect positive impact on me.

I would like to express my deepest gratitude to my supervisor, Professor Jonathan Histon, whose encouragement, attention, and patience guided me and made this work possible. He taught me how to be a better student and researcher, which I would not have learnt without his knowledgeable insights and unbiased criticism balanced with occasional praise. Professor Histon, I was so fortunate to be under your supervision, and I only hope one day I can be to my students the teacher you have been to me, thank you!

My sincere thanks and gratitude is also extended to my co-supervisor Professor Stacey Scott for her guidance, wise advice, and insightful and interesting discussions.

I would like to thank my readers Professor Catherine Burns and Professor John Zelek for their valuable and constructive comments on my thesis.

I would also like to thank my colleagues at HCOM, CSL, AIDL labs whom I was fortunate to meet and benefit from.

To my air traffic controller participants, thank you for your contribution to my research, and for the time you spent providing thorough explanations to my questions.

Eric, Ali, and Saud thank you for your programming and coding support. I am also grateful for Riley Duke and Michael Dereje for their amazing technical support; without their help I would not have been able to complete this project.

In addition, I would like to acknowledge Amirah and Mylene for their willing to help in preparing the initial setup of the experiment and assisting with the initial pilot tests of the experiment.

A very special thank you is dedicated to Nima Hashi who was my co-experimenter until the end of the experiment, and who performed her assistance tasks professionally. Thank you so much, I am grateful to you, Nima!

Of course, my warmest appreciation goes to my parents and siblings. Your unconditional love and emotional support every single day were invaluable. Mom, you might not have noticed that when I shared some aspects of my work with you, your curiosity and concern always initiated lots of conversations, to which you sometimes provided suggestions and solutions. I feel lucky to call such a bright woman my mother. Dad, pursuing my master's degree is the least I could do to make you proud. Thank you both for your endless prayers and unwavering encouragement and for the sacrifices you have made to help me grow.

Foremost among the individuals to whom I am thankful is my elder brother, Bandar. I am indebted to him for his untiring support and concern before and during our expatriate life in Canada. Truly, it is impossible for me to fully express the extent of the gratitude I owe to him. Bandar, words are not enough to thank you and pay you back! As well, words are not enough to thank my sister-in-law, Meshael Almasoud for her encouragement and concern, and to my little niece Manal. Hearing her giggle was a true joy and relief.

Finally, I would like to sincerely thank King Abdullah Al-Saud for supporting me and other Saudi students with generous scholarships through the King Abdullah Scholarship Program. My thanks are also extended to the Ministry of Higher Education in Saudi Arabia and to all the staff members at the Saudi Cultural Bureau in Canada; in particular, the Cultural Attache Dr. Ali Albishri, Ms. Hala Al-Hajeb, and Dr. Muhammad Najem.

## **Dedication**

*To my parents, Abdullah and Latifah,*

*To my brothers, Bandar, Adel, Meshal, and Abdulaziz and to my lovely sister, Albandari,*

*To my country, Saudi Arabia,*

*I dedicate this work to you.*



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## List of Acronyms

<b>ATC</b>	Air Traffic Control
<b>CPDLC</b>	Controller-Pilot-Data-Link Communications
<b>NextGen</b>	Next Generation Air Transportation System
<b>TRACON</b>	Terminal Radar Approach Control Facility
<b>VSCS</b>	Voice Switching Communication System
<b>WAIT</b>	Working Awareness Interruption Tool

# Chapter 1

## Introduction

Synchronous interactions and communications take place in individuals' daily life. During these interactions and communications, interruptions occur. Often, the interruptions are useful, providing information that is needed or desired; however, sometimes interruptions are distracting and disruptive. Moreover, interruptions can lead to errors, especially when they occur frequently or during critical times (Chevalley, 2010).

Fortunately, improved communication technologies are making it easier for people to interact and to interrupt each other. One of the important design considerations for communication technologies is the ability to control interruptions and the frequency of interruptions in order to minimize their negative effects. For instance, many systems and interfaces allow operators to manage interruptions by permitting, delaying, or rejecting them. This can be as simple as a mute button on a telephone or setting a status on a chat application. However, often the operator must manage interruptions without knowing the urgency of the incoming communications and must spend some effort discovering what the interruption is about before being able to manage it. Failure in interruption management in such a situation is often described as the "alarm problem" (Woods, 1995). Similarly, for an operator seeking to interrupt a colleague, there are typically few explicit ways of conveying the urgency of the interruption. It is also difficult to determine the availability of that colleague in order to time the interruptions effectively.

While systems have adapted and created ad hoc ways of controlling and managing interruptions, advances in communication technologies are creating opportunities to provide new tools for

enhancing operator situation awareness and interruption management. Consequently, these systems can help overcome the negative effects of interruptions. At the same time, it can be challenging for an operator who needs to interrupt a colleague to know when to time their interruption.

Collaboration between multiple operators, often separated by distance, is a critical element of many complex socio-technical systems such as medicine, transportation, and process control. Collaborative activities involve requesting, sharing, and distributing information in order for individual operators to perform their tasks. Therefore, operators of these systems must regularly and frequently deal with interruptions from collaborators. These interruptions can provide valuable information relevant to the task at hand and are needed for smooth system functioning; however, they can also divert attention and demand resources at inopportune moments. Moreover, interruptions can have negative effects that can be catastrophic. For example, interruptions by air traffic controllers while flight crews were in the middle of pre-flight checklists were contributing causes to both the crash of Northwest /Airlines flight 255 in Detroit in 1987 (NTSB, 1988) and the loss of Spanair flight 5022 in Madrid in 2008 (CIAIAC, 2008).

The research in this thesis explores interruptions in air traffic control (ATC) domain. ATC is an example of a dynamic and collaborative system where new technology could be introduced to better support interruption management by operators. Air traffic controllers are subject to and produce frequent and variable-urgency interruptions. Controllers communicate with each other to exchange, request, or provide information that may be of different levels of importance to the sender and receiver.

## **1.1 Research Problem**

Air traffic control is undergoing rapid changes in operating concepts, tools, and procedures. The development of “NextGen” technologies is creating opportunities to introduce new tools to help controllers better manage interruptions (FAA, 2013b).

Controllers are assigned specific areas of airspace and must cooperate to handle communications that range in priority from aircraft requests and inquiries on weather or turbulence conditions to emergencies and control instructions needed to change aircraft trajectories. These communications occur in parallel with the provision of on-going separation and control tasks for aircraft within their own airspace.

During the investigation of the nature of interruptions that occur particularly between controllers across facilities, it was found that there are currently only a limited number of techniques available to assist the controllers in managing interruptions. Specifically, the tools and displays that controllers use to communicate have few features that show the availability of controllers to other potential interrupters (controllers). On the other hand, controllers who need to interrupt a colleague do not have ways of conveying the urgency level of their interruptions.

### **1.1.1 Communication between Controllers in ATC**

In order to understand the challenge of interruptions in ATC, the following section briefly describes current air traffic controllers’ communications in terms of location and mediums.

Controllers in ATC are assigned specific responsibilities based on the positions they hold. For example, “The local controller is primarily responsible for the separation of aircraft operating within the airport traffic area and those landing on any of the active runways” (Nolan, 2011, p. 239), whereas

“a [radar controller’s] responsibility is to separate participating aircraft using a radar-derived display” (Nolan, 2011, p.237). Local controllers work in the ATC towers side by side with other types of controllers such as “ground controllers,” while radar controllers work in ATC terminals and centers assisted by “radar associate/non radar controllers.”

Therefore, controllers in air traffic control environments can be classified, in terms of location, as the following: within facility co-located, within facility non co-located, and across facility non co-located controllers.

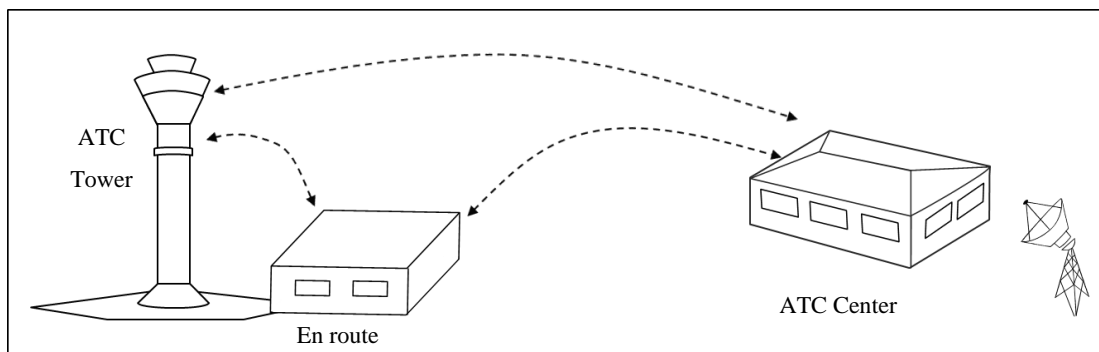
***Within facility co-located controllers*** sit next to and can see each other. This allows them to use cues such as body language and have the ability to see their colleague’s screen and overhear interactions with other participants in the system.

***Within facility non co-located controllers*** work in the same building, but they are separated by a row of screens, walls, or floors. Figure 1.1 demonstrates both co-located and non co-located controllers in a radar control room that would be found in a terminal or en route ATC facility. In this figure, controllers are situated in a way that supports the collaborative work of controllers; controllers whom working-airspace is next to each other are generally seated in the same “bank” or contiguous block of monitors and displays. However, due to the vertical and lateral divisions of airspace, there will always be some situations where controllers sitting in different rows or at opposite ends of the “bank” will need to interact with each other. In these cases, the controllers may work in the same facility, but they do not have access to the same visual and non-verbal communications as co-located collaborators. However, working in the same building can provide opportunities for off-duty interactions and relationships, which can have effects on collaboration styles and effectiveness (Davison et al., 2001).



**Figure 1.1: Co-located and non co-located controllers at a TRACON facility. Adapted from (Learmount, 2010)**

Finally, *across facility non co-located controllers* work in different facilities separated by distance. They could be in different buildings, cities, or countries. Figure 1.2 depicts an example of non-co-located communication practices between controllers located in different buildings.



**Figure 1.2: An example scenario of the communication transmission across facility – between controllers in ATC tower, en route, and center**

Controllers communicate in several ways; they typically use a method that allows them to transmit messages effectively and in a short-timely manner. The different contexts that controllers work within and the different relationships to other controllers mean a variety of methods are used. For instance, co-located controllers have the advantage of combining direct auditory communication with the

awareness of nonverbal communications of other controllers. Indeed, nonverbal communications as gestures as well as facial cues support verbal communication of the co-located controllers because they “[allow] an added range of information conveyance” (Wickens & Hollands, 2000, p. 232). Additionally, as a way of communication, co-located controllers can transfer messages through exchanging data objects such as the manual or electronic “flight progress strips” (FPS) which is a tool that “carries the basic details of each aircraft’s flight plan” (Smith, 2010, p. 44). Controllers communicating with other controllers in a different facility can also take advantage of these electronic tools; however, direct communication between controllers in different facilities is primarily reliant on verbal (auditory) communications through phone calls and radio calls. Unfortunately, the lack of visual feedback makes it harder to gain situational awareness of the availability status of the controllers on the other side of communication.

Verbal communication between controllers across facility implies that interruptions could occur at inappropriate times. This is because interrupters lack visual awareness information of the controller being interrupted, which might affect this controller’s workload or performance.

## **1.2 Scope of the Thesis**

There are many different types of communication between ATC personnel and other stakeholders in the system. While these communications vary in terms of location, position, and occupation, this thesis focuses on ATC controllers’ communication with each other; specifically, non co-located controller - controller communications and interruptions that are transmitted via the Voice Switching Communication System (VSCS), which will be discussed in detail in the next chapter.



### 1.3 Research Objectives

The following research question is the focus of this thesis:

*In time-critical, dynamic and collaborative environments, like ATC, what awareness-assisting techniques would allow for better management of the timing and presence of interruptions of and by other operators?*

More specifically, the thesis explores techniques that could be used in ATC settings to communicate:

1. *The availability of a controller being interrupted and*
2. *The urgency level of an interruption*

As mentioned earlier, controllers face interruptions frequently during their work. Supporting the controllers' situation awareness through a system, a technique, or a tool is a way to address the research problem. To create an efficient interruption management system, it should provide pieces of information that could be implemented to provide adequate awareness. The goal of the thesis is to develop a tool that would help reduce the negative impact of interruptions by providing indications of the availability of a controller and the urgency level of a call for both sides of an interruption.

To answer the abovementioned research question, three specific objectives are identified and described below. In order to develop the awareness tool, first, the way the communications and interruptions occur between controllers in real ATC environments must be well understood. To accomplish this, key factors that affect the situational awareness of controllers, as well as sources of interruptions and aspects of controllers' busyness must be investigated. The following are the three objectives of this thesis:

**Objective 1 - *Identify existing techniques that the controllers use to gain interruption situation awareness and identify the factors that cause inefficient interruption management.***

The results of achieving Objective 1 were used to identify opportunities to improve interruption management for controllers. This leads to the second objective, which was to develop new features supporting interruption situation awareness that could be incorporated into existing controller communications screens.

**Objective 2 - *Investigate potential improvements to the developed design of controllers' communication screens that would help support interruption awareness.***

This objective was achieved by conducting interviews and “Participatory Design” sessions with subject-matter experts. Feedback about the initial prototype designs in terms of practicality and acceptability was obtained.

**Objective 3 - *Evaluate revised versions of the developed features using a user based experimental methodology.***

The collection of new features was inserted into a display emulating existing communication screens. The combined package is referred to as the WAIT (Working Awareness Interruption Tool). The new tool was evaluated for its relevance in supporting interruption management. Based on the evaluation of the developed features, enhancement and limitations of the tool design are suggested as part of future work.

## **1.4 Contributions**

In achieving the objectives described above, the thesis makes the following contributions to the field:

- Identifies features (availability and urgency) applicable to introducing interruption management tools in the ATC environment.
- Demonstrates for a limited sample size of student participants that the provision of availability and urgency features shows improvements in performance (objective and self-perceived) and reduces the distraction effects of interruptions from other operators
- Creates a methodological contribution by demonstrating a design for interruption experiments for complex dynamic systems.
- Provides a foundation for designing and implementing future interruption management tools in air traffic control environment.

These contributions are a stepping stone for additional studies to investigate interruption management in time-critical complex environments like Air Traffic Control.

## **1.5 Thesis Overview**

The remainder of the thesis is organized in the following way:

- Chapter 2, Background: discusses previous work on interruptions and situation awareness in both regular and complex systems environments.
- Chapter 3, Developing an understanding of interruption management in air traffic control: describes site visits to ATC facilities and observations of existing tools and interruption management practices and controllers contributions to a questionnaire. It also summarizes the important observations relevant to the design of an interruption management tool.

- Chapter 4, Design and initial evaluation of an interruption management prototype: describes the developed initial prototypes of the WAIT tool and the feedback elicited through the Participatory Design sessions with the subject-matter experts.
- Chapter 5, Experimental platform and design of the experiment evaluation: discusses the improved WAIT tool used in the study. Additionally, it presents the test-bed and the study's physical set-up. Finally, it presents the tool's design challenges and the modifications and simplifications made to the experiment.
- Chapter 6, User-study analysis, results, and discussion: explains the evaluation methodology used. Also, it discusses the analysis and results of the user study.
- Chapter 7, Findings and future work: draws conclusions from the results of the experiment and thesis and proposes long-term future work.

## Chapter 2

### Background

The background chapter provides a review of previous research work relevant to the main fields of study of this thesis: interruptions and Situation Awareness (SA).

#### 2.1 Interruption

The “interruption” concept has been studied in many fields such as psychology (Shum et al., 2013; Ledoux, 2003), engineering (Lu, 2005), and computer science (Hodgetts & Jones, 2007; Khalil, 2006), and it is associated with other concepts such as “multi-tasking” (Law, 2004). Many researchers have worked on creating a formal definition of interruption. For instance, McFarlane (1997) gave a general definition of it as “the process of coordinating abrupt changes in people’s activities” (p. 67). While the information provided through interruptions can be valuable and task-relevant, they also create distractions and consume attention resources (McFarlane & Latorella, 2002). Interruptions are known to have impacts on task performance (e.g. Rogers & Monsell, 1995). There has been substantial previous work on technologies for controlling interruptions (e.g. Wiberg & Whittaker, 2005). The following subsections discuss this previous work in more detail.

##### 2.1.1 Effects of Interruption

Interruptions can generate positive effects; for example, Van Bergen’s (1968) review of decades of interruption research in psychology found that people could more easily recall items from interrupted tasks than from uninterrupted tasks. However, more recent research has found that interruptions affect task performance negatively, and they can produce errors that cannot be overcome afterwards. For example, McFarlane and Latorella (2002) showed that interruptions can induce stress, increase the

time it takes for people to resume working on an interrupted task, and increase task errors. Moreover, Adamczyk et al. stated that interruptions can cause annoyance and frustration (2004). Additionally, interruptions were found to have an effect on work accuracy (Flynn et al., 1999) and people's behavior (McFarlane, 2002). Interruptions can also appear to slow or set back the performance of tasks (Bailey et al., 2001; Perlow, 1999; Kreifeldt et al., 1981).

### **2.1.2 Controlling and Managing Interruptions**

To mitigate the negative effects of task resumption after interruptions, techniques have been developed to assist people on the interrupted task. For instance, providing a list of historical events (St. John et al., 2005), video or instant replay (St. John et al., 2005, Sasangohar, 2009, Scott et al., 2006), and cues that mark the last action location before interruption (Trafton et al., 2005).

These techniques focus on facilitating task resumption after an interruption has occurred. Interruption management, however, also concerns facilitating the pre-interruption phase to determine, for example, whether an interruption should be initiated or responded to at the given time. The rapid growth of various communication tools (e.g. answering machines, voicemail) and social communication applications (e.g. Google Talk) also foster new and innovative ways to support interruption management. These social tools usually provide their users with an awareness indicator that allows them to set their status either from built-in statuses such as "Away," "Busy," and "Available," or custom statuses while answering machines and voicemail systems give people the opportunity to postpone an interruption until a more appropriate time. Such techniques provide awareness features that assist interrupters by giving them insight into the availability of the person being interrupted.

The rapid adoption of such tools in the personal computing domain motivates the question of whether implementing similar techniques could be effective in more complex domains.

The next subsections discuss previous researchers' contribution in developing techniques to control and manage interruptions.

#### 2.1.2.1 Awareness displays or visual cues of interruptees status

Previously developed techniques to enhance awareness and provide visual cues of interruptees status have been as simple as the visual status indicators provided in social applications or on the display screens of telephones. Isaac et al. (2002) showed that “[visual] cues are better for providing an overview of information but only when a person chooses to attend to them.” In their study, they developed a text-based social application and equipped it with awareness techniques that provide users with more “opportunistic interactions.” They tried to overcome the problems that commonly exist in previous attempts to use visual cues to convey an interruptee’s status.

To illustrate, in many system applications, when a user sets her status as active but does not use the application for a long time, the status indicator is rendered useless because it does not show the current and real-time situation of that user. One of the features that Isaac et al. has developed is specifying the user as active if the application is used within the last 5 minutes. The intensity of busyness is also represented by the amount of tactile interaction with the device in a specific period of time. Therefore, if this indicator is empty for more than 15 seconds, it means that there is no activity with the device, meaning that the user is not engaged in a conversation with other users.

Similarly, Dabbish and Kraut stated that “[awareness] displays are designed to encourage communication, while minimizing the disruption associated with interruption by displaying a target’s

current state” (2004). In their experiment, they proposed a technique of providing an awareness display of potential interruptees in order to influence the appropriate regulation of interruptions, which would thus lead to better timed interruptions. They provided participants with three display variations that showed the state of potential interruptees: a live view of current working tasks, abstract, or no awareness display. To summarize this experiment, it was found that the interruption timing was improved in both awareness displays; however, participant’s performance decreased when the live view display was used, likely because of the extra cognitive processing required. Also, the results of this experiment showed that when an interrupter and interruptee have joint goals, their overall performance was better than if they had individual goals. The latter point is important for the design of interruption management tools because in many cases, the interrupter benefits from the interruption more than the interruptee. In ATC environments, a shared goal between controllers is to maintain the safety of aircraft. In a similar fashion, Hudson et al. (1996) investigated the effects of using different media awareness techniques (video, audio, or still images) that transfer potential interruptees’ activities (in distributed workplaces) in order to control communications between colleagues. In their study, they were mainly concerned about the effect of these techniques on privacy and the disruption caused by the transferred information.

#### 2.1.2.2 Time optimization

Another approach to manage and control interruptions is based on allowing the interruptions to occur at certain times. Perlow conducted a field experiment to study the interruption management of software engineers at work. She suggested optimizing the use of working time by postponing interruption activities and resume accepting and receiving the entailed activities to a pre-assigned interactive time (1999). Although this mechanism was effective to some degree, the engineers were



not able to maintain it for several reasons; for example, some interruptions are urgent in nature and cannot be delayed to be processed in the “interactive time.” Another study was conducted by Bailey et al. in the same manner (2001). They tested the effect of initiating interruptions in two cases: the first case is interrupting participants between main tasks where the load on the memory is minimized. In the other case, participants were interrupted during the performance of main tasks where the memory is occupied with the engaging task. The result of this experiment showed that the best time for interruption should be during the time of “low memory load” or during a “delayed system response” (Bailey et al., 2001). The studies in this area (time optimization) had huge contribution from researchers (e.g. Adamczyk et al., 2004; McFarlane, 2002; and Cutrell et al., 2001). They all focused on investigating the opportune timing of interruptions and the effect of interruptions occur at different times within task execution process.

### **2.1.3 Interruptions in ATC-Like Environments**

Interruptions are common in time-critical, dynamic, and collaborative environments, such as ATC. However, there has been relatively little work done in applying these techniques to the fast-paced, collaborative, and distributed safety critical operations that occur in air traffic control, in part because of the challenges of integrating with other task demands in such a complex operational environment. There are many sources of interruptions in the ATC environment such as phone calls and radio calls from other controllers or pilots. Interruptions in ATC have attracted research interest, primarily in the area of the presentation of incoming interruptions. For example, Ho et al. (2004) studied the provision of information on the nature and urgency of an interruption using different modalities. Jayaraman (2011) studied multi-modal, including tactile, notification techniques in ATC contexts. However, previous work has primarily focused on generating a fundamental understanding of interruption

processes using simplified or simulated ATC environments. For example, in Ho et al.'s (2004) simulated ATC environment, the task associated with the interruption was constant and contrived (counting stimulus patterns), and there was no interaction with other human operators. The limits of this previous work suggests there is an opportunity to consider the practical implications and opportunities for design to manage interruptions within the existing systems and displays used in current ATC operations.

Applying the techniques that are discussed above can be restricted or inconsistent with other task demands in complex operational environments, such as ATC communication system. To illustrate, in order to manage interruptions in an ATC environment, it is clear that applying the visual and awareness techniques to an ATC communication system is more applicable due to the dynamic nature of information in such systems. Also, delaying or postponing urgent interruptions could create a catastrophic accident.

## **2.2 Situation Awareness**

Information is highly dynamic and takes on great importance in complex systems; there are often rapid and frequent updates in these systems. The responsibility of operators in such systems is a daunting task, as they have to track rapid changes of information, and filter and understand it before it is replaced. Accordingly, awareness of the environmental cues and the ability to understand their current and future meaning for its relevant task is a key to a successful decision making process and ultimately effective task performance (Endsley, 2001). Situation Awareness has been formally defined by Mica Endsley as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley et al., 2003). The success of decision making is affected by achievement of the

different levels of Situation Awareness, namely, perception level, comprehension level, and projection level, respectively. The first level of SA is the perception level, which is about keeping up with relevant environmental elements using a single or a combination of the five senses. Perception level is followed by the comprehension level, which is achieved by understanding what the perceived environmental cues mean in relation to the pertinent goals. Finally, the projection level can be described as the process of predicting what these perceived and comprehended cues will do in the future (Endsley et al., 2003).

### **2.2.1 Application of Situation Awareness to the Project**

Sarter and Woods state that Situation Awareness is “an essential prerequisite for the safe operation of any complex dynamic system” (1991). Situation Awareness is a common concept in the world of Air Traffic Controller where it is referred to as “the picture,” which means the controller’s mental model of the current and the future situation of a task on which decisions are hinged (Endsley, 1997, p. 2). However, Isaac et al. have stated in their book, published in 1999, that little research about SA in ATC has been done. With the understanding of how SA is gained by ATC controllers during the communications transmission and the challenges and limitations that the controllers face to gain it, developing the design of the communication system between controllers in a way to enhance SA is essentially required (Endsley et al., 2003). Therefore, creating, developing, or improving the design of a new system entails a good understanding of the dynamic SA requirements rather than the “static knowledge” or rules that the controllers must possess or follow (Endsley et al., 2003).

It is important to note that in the aviation domain, most of the problems occur in SA first level; less problems occur in the SA second level, and finally, the least amount of problems occur in the SA third level (Endsley et al., 2003, p. 16-19). This fact should get the attention of systems designers to

find, through the analysis of SA requirements, what causes the inappropriate perception of the cues. The failure to perceive these cues is not only because they are not available, but it could also refer to their unsuitable availability or because of the information cues overloading, which makes it hard for the user to filter the needed information.

It is apparent that the factor that causes negative impact of interruptions on controllers can be a failure in any level of SA. For example, if an interruption did not get an appropriate response and there was a subsequent problem, it could be a result of a failure in perceiving the cues that shows the high urgency level of the interruption. Examples of the available environmental cues that controllers use when communicating with each other are the communication means used and the voice pitch, and the status history of communicated controller. If all the cues were perceived, but a failure occurred, it might refer to the lack of understanding of what the cue meant; this is associated with the second level of SA. For instance, being interrupted by a controller who speaks with a loud, high pitched voice or receiving a call from an irregular means of communication should be an indicator to an interruptee of the critical situation of the interrupter. For the third SA, a failure might occur in the projection phase, which would lead to wrong decisions and then result in the failure of the task.

## **2.3 Summary**

In summary, techniques such as status indicators in chat applications are a common way to manage, control, and regulate interruptions in many fields. Such techniques are not currently used to manage interruptions in ATC environments. The ATC environment, with its domain-specific existing communication interfaces, and real-time communication of safety critical information, represents a new type of environment; the importance of that information and the potential negative effects of

interruptions means there is a promising opportunity to investigate if and how interruption management could be improved within the ATC domain.

In addition, interruptions were shown to be closely linked with the concept of Situation Awareness. Interruptions can both provide information that informs situation awareness, and create distractions that can degrade situation awareness. Loss of situation awareness is a commonly identified concern in the aviation field and there is continuing interest in the field to develop techniques for enhancing operators' ability to develop and maintain it.

The review of previous work on interruptions in ATC shows that there has been only limited work done, consisting primarily of idealized conditions with non-representative interruption tasks. For example, the studies included tasks that were much simplified, and that used non-task representative interruptions. As well, there has been very little systematic study that recreates the dynamics of interaction with other human participants. Therefore, there is research needed for the identification and development of techniques that would help in the management of interruptions in environments representative of the ATC task, including the "messiness" of interacting with other dynamic human operators. The next chapter discusses the methodology used to gain an understanding of interruption management in air traffic control in order to create the initial vision of an interruption management tool.

## Chapter 3

# Developing an Understanding of Interruption Management in Air Traffic Control

Previous chapters of this thesis have provided background information on some aspects of the air traffic control (ATC) environment, as well as on interruptions in different fields including complex systems and ATC-like environments. As described in Chapter 1, a key objective was to understand existing communication practices and interruption management tool strategies in ATC. In order to determine how the design of communication systems impacts the way the controllers handle interruptions, it is important to understand the ATC controllers' communication process to identify how existing communication tools the interruption management in ATC, and to determine the available cues in the communication system that provide controllers with situational awareness.

This chapter describes field observations of communication and interruptions between controllers in air traffic control facilities. The goal was to determine with whom they communicate, why, and through what means the communication occur. Also, the aim was to identify the nature of interruptions and how controllers deal with interruptions while communicating with other controllers.

ATC field observations allow researchers to observe controller - controller communication processes directly, enabling the identification of important and often subtle factors affecting interruption management. Initial data collection methodologies, such as questionnaires, were also used to investigate the communication and interruption challenges in ATC facilities, and the results are presented in this chapter. The follow-up interviews with air traffic controllers (discussed in the next

chapter), as well as the designs for communication tool modifications (discussed in Chapter 5), were inspired by the results reported in this chapter.

### **3.1 Methodology**

In order to develop insight into the communication between ATC controllers, observing controllers through site visits at three ATC facilities in North America were made. Two of these facilities were control towers, and the other was an en route center responsible for aircraft flying in airspace not controlled by air traffic control towers. In addition, a questionnaire was distributed to air traffic controllers to gather additional information about ATC communications and interruptions.

#### **3.1.1 Site Visits**

Observing operators while performing their work tasks in real environments offers several benefits. Field observations are advantageous because they provide the opportunity to see how workers operate in the workspace that they are used to and familiar with; consequently, they “can provide data rich in detail and subtlety” (Tayie, 2005, p. 89). Certain types of information may not be identified using other research methods (such as interviews) because when people are asked to speak about their work performance, some aspects of the work could be unconsciously skipped in their answer. Based on that, unobtrusive field observations of controllers and specialists controlling traffic in tower and en route facilities was used as the initial data collection methodology.

An airport tower is “a tall, windowed structure located on the airport grounds” (“Air traffic control,” 2013, “Airport control,” para. 1). The tower cab, which is on top of the tower, is a round windowed space from which controllers perform control tasks to the aircraft in the immediate environment of the

airport. The controllers use the view from the windows and sophisticated electronic devices to make control decisions affecting the movement of aircraft in the air and on the airport surface.

Controllers at the towers communicate with the controllers responsible for the airspace above and near the airport. The controllers responsible for the airspace above and near the airport work in facilities called Terminal Radar Approach Control (TRACON)s in the United States or terminal specialties in Canada. TRACONs are a stand-alone facility while terminal specialties are parts of larger en route facilities. In both TRACONs and terminal specialties, controllers work in “a windowless radar room either below the tower cab or somewhere else in the area, [from which a controller] controls aircraft in the wider region of space around the airport” (Wickens et al., 1997, p. 34).

As mentioned, the site visits were conducted at two towers and one en route center. During the observation tours, the controllers explained many technical terms and showed some of the context artifacts and equipment used to assist them in their daily work. The following subsections describe each visit.

#### 3.1.1.1 Airport 1

The first airport visited is a small, primarily general aviation airport with limited commercial traffic; it is also a designated international airport. The airport has daily and weekly domestic and international flight services. Several commercial airlines serve the area of the airport. Also, it is the home of several flight schools. Based on aircraft movements, it is consistently in the top twenty busiest airports in its country.

The visit to this airport comprised of a tour of the airport tower facility. At the commencement of the



tour, a short meeting was held with the unit specialist of the facility to guide the visit team through the ATC tower space. He talked about the control tasks briefly. After that, the visit team moved with the unit specialist to the tower cab where controllers perform their control tasks and communicate with other controllers within the same facility and controllers across facility. About four controllers were observed; they were working at different control positions, and their experience level varied between being trainees and fully qualified controllers. The visit lasted approximately two hours.

### 3.1.1.2 Airport 2

Airport 2 is a very large, busy, major international airport in North America. It is a hub airport with more than 300,000 flights annually. Two main types of facilities were observed at Airport 2: the tower and the terminal specialty in the en route center.

At the tower, a brief meeting with the Unit Procedure Specialist was held. Afterwards, the visit team moved to the tower cab where operations and controllers of different positions were observed during the performance of their control tasks. About six controllers were observed; they were working at different control positions. The visit lasted approximately two hours.

The terminal specialty was also visited; here a guided tour with the Unit Procedure Specialist within the facility was received. Additionally, interaction with subject-matter experts and observations of ATC operations from a distance were made. Observations were made of the arrangement of the controllers within the workspace and the need for inter-facility and across-facility communications.

The last station of the terminal specialty tour was in the ATC simulation room where trainees receive their ATC training. The Unit specialist made a thorough explanation of the tools, equipment, and displays used by controllers. In the simulation room, there was also an opportunity to observe some

screen displays and ATC equipment closely without distracting any of the personnel. For example, the typical paper “Flight Progress Strips” tool was shown, and the process of creating and moving the strips between controllers was explained. Nowadays, electronic versions of these strips are being introduced in order to reduce the voice communications between controllers. Furthermore, the Unit Procedure Specialist demonstrated the simulation radar screens, some of its properties, and the type of data shown on it.

During both site visits, a series of questions concerning the viewed space were asked to the personnel to gain insight into:

- The nature of interruptions that occur in the field
- How controllers respond when being interrupted by other controllers
- The means of communication between Controllers
- The different displays used by controllers
- The contextual cues used to gain situational awareness of other sectors and controllers.

### **3.1.2 Questionnaires**

Once the site visits were completed and preliminary data was collected, additional data on specific use-cases involving inter-controller communications and interruptions was identified as an important research need. To gather this data, a questionnaire was developed, which contained a series of open-ended questions to obtain illustrative examples of interruption incidents and basic information of the ATC communications such as the reasons for the communication and means used to deliver the communications. This was followed by a question asking for suggestions for developing a tool that would assist controllers in interruption management. The responses were elicited through the self-report method, which are questionnaires (see Appendix A for a copy of the questionnaire) that rely on

participants to “[generate] data on their own” (Crandall et al., 2006, p.14). The controller participants were free to leave any questions blank if they did not feel comfortable answering them.

### 3.1.2.1 Controller Participants

Retired or active air traffic controllers were recruited to participate in this study. In order to participate, controllers were required to have experience working in ATC towers as ground or local controllers, or in ATC centers as radar controllers. Participation was voluntary and the controller participants were not remunerated for their involvement. Two male controllers participated in the study. One was an active controller, and the other one was a retired controller. Both controllers have more than 10 years of experience, and they were from North America.

## 3.2 Observations Relevant to Design of an Interruption Management Tool

The next subsections summarize the observations from the ATC site visits that were determined to be the most relevant to the development of an interruption management tool. The observations were drawn from the observing of controllers in their daily work, and the tools and techniques that they used. The observations presented are synthesized with the responses to the questionnaire to highlight the most relevant considerations for the design of an interruption management tool.

### 3.2.1 Control Positions

There are different types of controlling positions in the ATC facilities. For example, air traffic control towers (Figure 3.1) house controllers such as Ground, Local, and Clearance Delivery controllers who address flight control issues for aircraft within the tower’s identified airspace (Figure 3.2). Controllers at a terminal specialty or TRACON (Figure 3.3) are either data or radar controllers; these controllers direct the movement of aircraft leaving the tower airspace all the way until reaching en route facility

airspace. Similarly, data and radar controllers are housed in en route facilities; however, they deal with aircraft at high altitudes (Figure 3.4). The communication between an aircraft during its flight and the above mentioned air traffic control facilities can be seen in Figure 3.5.



**Figure 3.1: An airport traffic control tower.**  
Adapted from (Carey, 2013)



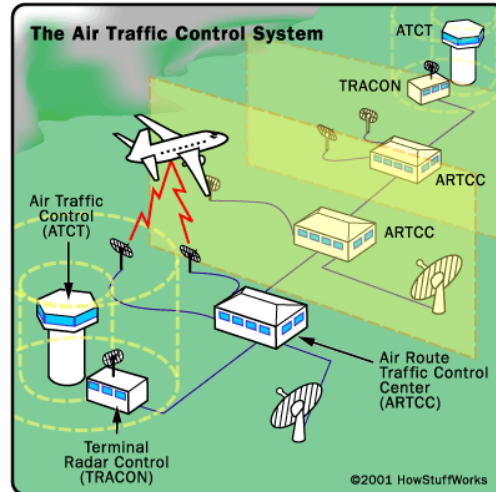
**Figure 3.2: Air traffic controllers at a tower.** Adapted  
from (Greenall, 2012)



**Figure 3.3: A TRACON facility.** Adapted from (K.  
Dixon Architecture PLLC, 2012)



**Figure 3.4: Controllers at a TRACON facility.** Adapted  
from (Learmount, 2010)



**Figure 3.5: The various air traffic control facilities encountered by a plane during its flight. Adapted from (Freudenrich, 2001)**

### **3.2.2 Means of Communication**

Controllers can communicate visually with co-located controllers. However, for controllers working in physically separate locations, either within the same facility or in different facilities, they must communicate through a Voice Switching Communication system (VSCS) that has different communication functionalities. Controllers working in specific positions have certain ways to communicate with each other through the VSCS. Also, in some cases and positions, controllers communicate through the Manual or Electronic “Flight-Progress Strips,” either with co-located or across facility controllers. Details of these tools are described in the following section.

### **3.2.3 Control Display Screens**

Controllers utilize several types of screens, and each screen is used for a particular purpose. Different types of display screens were observed during the site visits such as: radar, Voice Switching

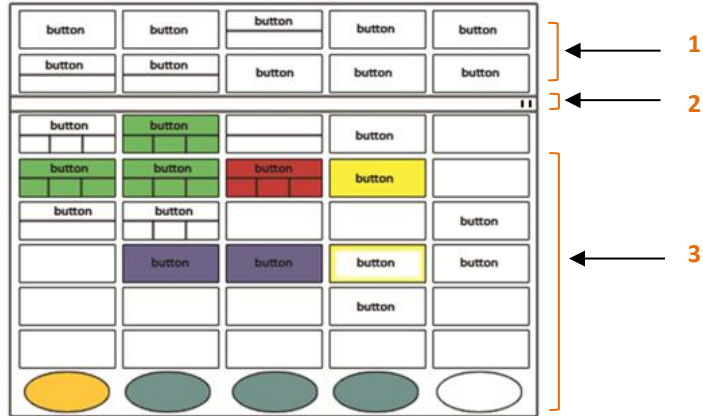
Communication System (VSCS), Electronic “Flight-Progress Strips”, and the airport runway and taxiway layout screens (see Table 3.1).

**Table 3.1: Observed screens during the visits**

Screen	Purpose
Voice Switching Communication System (VSCS) screens	<ul style="list-style-type: none"> <li>• Used to set up across facility controller-controller and controller-pilot communications</li> </ul>
Radar screen	<ul style="list-style-type: none"> <li>• Displays the distribution and flow of aircrafts in a towered airport or entire sectors</li> </ul>
Electronic flight progress strips screen	<ul style="list-style-type: none"> <li>• Used to track flights and pass on their information to related controllers</li> </ul>
Taxiway layout screen	<ul style="list-style-type: none"> <li>• Shows the aerodrome runways and taxiways</li> <li>• Shows the flying aircrafts within the near area of the airport</li> </ul>

### 3.2.3.1 Voice Switching Communication System (VSCS) screen

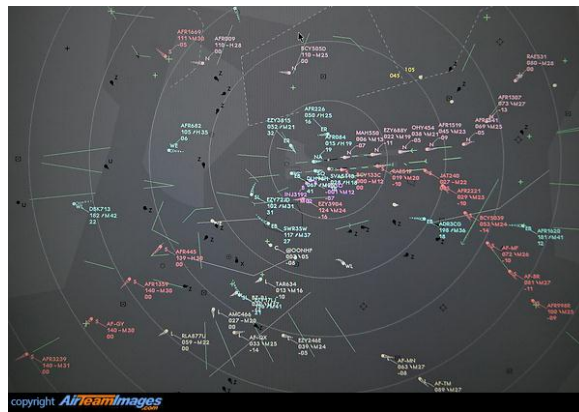
The Voice Switch Communication System is used to set up controller-controller and controller-pilot communications. The VSCS includes audio and touch devices. The touch device comprises the interface control panel; it has a function menu bar in the top part of it which has several functions such as the screen personal configuration (see Figure 3.6, labeled area “1”). Beneath the function menu bar is a message bar (the thin area labeled as “2”) to display specific information about status or errors. The third part of the VSCS screen (“3” in Figure 3.6) is the operational display which consists of several rectangular and oval shaped buttons, each of which serves a certain purpose (radio, hot line, or telephone communication). Pressing these buttons allows controllers to communicate with other controllers or pilots by talking directly through the system microphone.



**Figure 3.6: Graphical representation of an existing VSCS screen. Adapted from (Transportation Safety Board of Canada [TSB], 2003)**

### 3.2.3.2 Radar Screens

Radar screens are used by radar controllers at centers and ground controllers at towers. The radar screen can be described as a dark map display that shows the distribution and flow of aircraft in a towered airport or entire sectors in which the information is updated dynamically. Each aircraft target is coupled with a tag of relevant data such as airline code, altitude, and speed (Figure 3.7). Also, radar screens allow the operators to calculate the separation distances between aircrafts.



**Figure 3.7: Aircraft Data tag on a radar screen. Adapted from (Bailleul, 2010)**

### 3.2.3.3 Electronic Flight Progress Strips Screen

Electronic flight progress strips screen is a touch screen used to annotate flight information in order to track flights and to pass their information on to other controllers, which provides controllers a passive way of communicating information. An example of an electronic flight progress screen is shown in Figure 3.8. Electronic versions are becoming more common but the typical paper form is still widely used. Data controllers at ATC centers and ground and local controllers at towers require this screen in their work. Figure 3.9 shows a data controller use paper flight progress strips.



**Figure 3.8: Electronic flight progress strip screen. Adapted from ("Air traffic control," 2013)**



**Figure 3.9: Data controller using paper flight progress strips. Adapted from (Learmount, 2010)**

### 3.2.3.4 Taxiway Layout Screen

Ground controllers at towers use this screen to view the aerodrome runways and taxiways. Moreover, this screen displays the aircraft and vehicle locations and their movements along the runways and taxiways. It also shows the aircraft flying in the immediate vicinity of the airport.



### 3.2.4 Situation Awareness Elements

Existing implementations of the VSCS displays, which target controllers depend solely on when communicating, provides limited awareness cues of the status of controllers or calls. However, during the site visits, the controllers demonstrated several techniques that provided them with contextual Situation Awareness (SA), which is important to perform their work. The next points show examples of the techniques used by controllers to gain SA.

- A portable transceiver was used in the smaller airport control tower. It has a small green light which lights up whenever the center radar controller's frequency is in use. The volume is muted so the only feedback provided is the visual light; there are no audio cues. This makes the tower controllers aware of the centers' controller status which allows for more appropriate interruption timing.
- A multi-channel standby radio transceiver that is used in case of power outages. When a radar controller's frequency is selected and whenever there is a transmission, a colored light comes on. If the light is continuously flashing on, it means that the controller is busy talking to aircraft.
- Radar screens show the traffic distribution in other sectors which helps to a certain degree in predicting the availability of the controllers controlling them; however, it doesn't convey how complex the situation a sector's controller is handling.
- The easiest cue that makes a controller aware of the availability status of another controller is the phrase "STAND BY" when a call is initiated. This phrase conveys that the controller being interrupted is occupied with a task that requires his/her attention and time without an interruption. The caller would know that ending the call is the proper response.

- Sometimes controllers in the center will work as a team, dividing duties between them. Local controllers are aware of this and can use knowledge of who answered different calls to determine how busy the center controller(s) are. For example, when a local controller calls the terminal controller for two separate purposes, with different levels of operational importance, if the same controller answers both calls, it could be interpreted as indicating that the terminal controller is not busy. If separate controllers answer the calls, it could be an indication that the terminal controllers are very busy.
- The voice tone transmitted in the call could determine its urgency. To illustrate, one of the controllers said about receiving an urgent call from another controller that “the tone of voice indicated that [the] message must take priority over anything else the controller [being interrupted] may have been doing.”
- If visible, for example in co-located interactions, the number of flight data strips and weather conditions also play a role in providing awareness of other controllers’ availability. Dealing with critical weather conditions is one of the first priorities of controllers.

### **3.2.5 Factors Making a Controller Busy**

Controllers were asked to mention the factors that make controllers occupied. The factors are summarized in the following points with no relative preference:

- Critical weather conditions: Thunderstorms
- Aircraft emergencies
- Volume and complexity of traffic in a controller’s area of responsibility
- Amount of coordination between facilities and agencies
- Combined operating positions for a single controller

### **3.3 Suggestions for an Awareness Tool Design**

The controller participants were asked in the self-reporting questionnaire to provide some design suggestions for a virtual communication tool that has features to provide controllers with situation awareness. The responses received were insightful, and the most relevant ones were the following:

- Create automated awareness features whenever possible to prevent adding workload to the controller.
- Features showing the willingness of controllers to be interrupted (see footnote in the beginning of Chapter 4) should include factors that represent controller's busyness, such as the current number of aircraft being worked at the sector.
- Whenever colors are used in the developed features, limited colors should be applied.
- Using simple and limited scale levels for features that have several levels.

The suggestions extracted from controllers were taken into consideration as guidelines for developing a tool prototype to provide improved interruption management.

### **3.4 Summary**

This chapter describes the field observations (site visits) and questionnaires that were used to collect data about the communications and interruptions between controllers in the ATC operational environment. The site visits took place at three major ATC facilities in North America. In these facilities, controllers were observed during their communications with co-located and non-co-located controllers. The use of a "self-report" questionnaire provided an easy and accessible way to developing initial insights about the research question.

Both the field observations and questionnaire provided insight into several things: controller's control positions, such as ground, local, radar, and data controllers; means of communication such as non-verbal communication, VSCS screens, and "flight progress" strips; control display screens such as VSCS, radar, "flight progress" strips and taxiway layout screens; and factors determining the busyness of controllers such as critical weather conditions, aircraft emergencies, and traffic complexity. A key finding that emerged across all of the observations is that there are limited, yet subtle available sources that provide controllers with situation awareness, but there was no specific tool or technique attached to the VSCS screens to convey awareness information about the interruptions.

The results from the methods described in this chapter provide strong evidence that there are opportunities to improve the interruption management processes in the ATC communication system. This will help in creating better communication means between non-co-located controllers using the VSCS. The following chapter presents the follow up interviews with subject-matter experts and discusses the initial prototype of the research tool.

## Chapter 4

# Design and Initial Evaluation of an Interruption Management Prototypes

The previous chapter describes site visits and questionnaires conducted at multiple North American ATC facilities (tower, en route and terminal) to gain an understanding of the ATC operational environment. The field observations and results from the methods described in the previous chapter show the limitations of current techniques that controllers use to gain situation awareness of the interruption, interrupters, and interruptees which may subsequently cause negative impact on a controller's performance. Based on the experience gained and after reviewing the previous literature, a first version of an awareness interruption tool was developed in which two key situation awareness features were incorporated into a simplified version of the VSCS communication tool. The two features are intended to help communicate a controller's availability to be interrupted and to convey the urgency level of interruptions.<sup>1</sup> Furthermore, these features would allow for more appropriate and efficient interruptions while at the same time mitigating the negative impact of the interruptions. The awareness tool that is integrated within the VSCS was given the name Working Awareness Interruption Tool (WAIT).

Section 4.1 describes the design process of developing WAIT. Section 4.2 presents a description of the initial prototypes of the features. Section 4.3 of this chapter then describes the Cognitive Task

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<sup>1</sup> Alqahtani and Histon (2012) previously described the initial prototype implementations for a controller's willingness to accept interruptions and an ability to set the priority of an interruption. Further reflection suggested the labels (willingness and priority) did not match the intended functions. The features are designed to reflect a controllers availability (rather than willingness) and the urgency (rather than priority) of an interruption. (Alqahtani et al., 2013)

Analysis (CTA) and Participatory Design (PD) methods used to evaluate the prototypes, followed by the results of the evaluation and the collected data.

## **4.1 Design Lifecycle**

The design process used to develop the Working Awareness Interruption Tool (WAIT) based on the observations and findings described in the previous chapter is shown in Figure 4.1. The process was iterative, with several traversals of the loop shown in Figure 4.1. The tool design started with a general vision based on the existing VSCS screens. After that, needs were identified and requirements were established (“1” in Figure 4.1) through the observation that took place at the site visits and questionnaires that were conducted with the controllers (Chapter 3). Based on the data collected from these methods, along with the literature review, and discussions with interested colleagues, new features that would fulfill the goal of the thesis were identified and several low-fidelity WAIT prototypes were developed (“2” in Figure 4.1).

In order to evaluate the prototype, interviews were conducted with controllers to gain more information about the interruptions and communications between controllers; these interviews also included a Participatory Design session (“3” and “4” in Figure 4.1) to elicit their insights into several low-fidelity WAIT prototypes (Chapter 4). The data collected helped to narrow down the number of proposed designs to the ones that seemed applicable. The WAIT prototypes then went through a continuous redesign process (including finding and fixing any encountered errors) to develop displays providing the essential functionality (“5” and “6” in Figure 4.1) while being consistent with the participants’ expected experience. High-fidelity prototypes (screens) were developed and tested through intensive pilot test sessions. Refinement and modifications were made to the final developed

experimental screens (“7,” “8,” and “9” in Figure 4.1) in preparation for a human-in-the-loop evaluation experiment (Chapter 5 and 6).

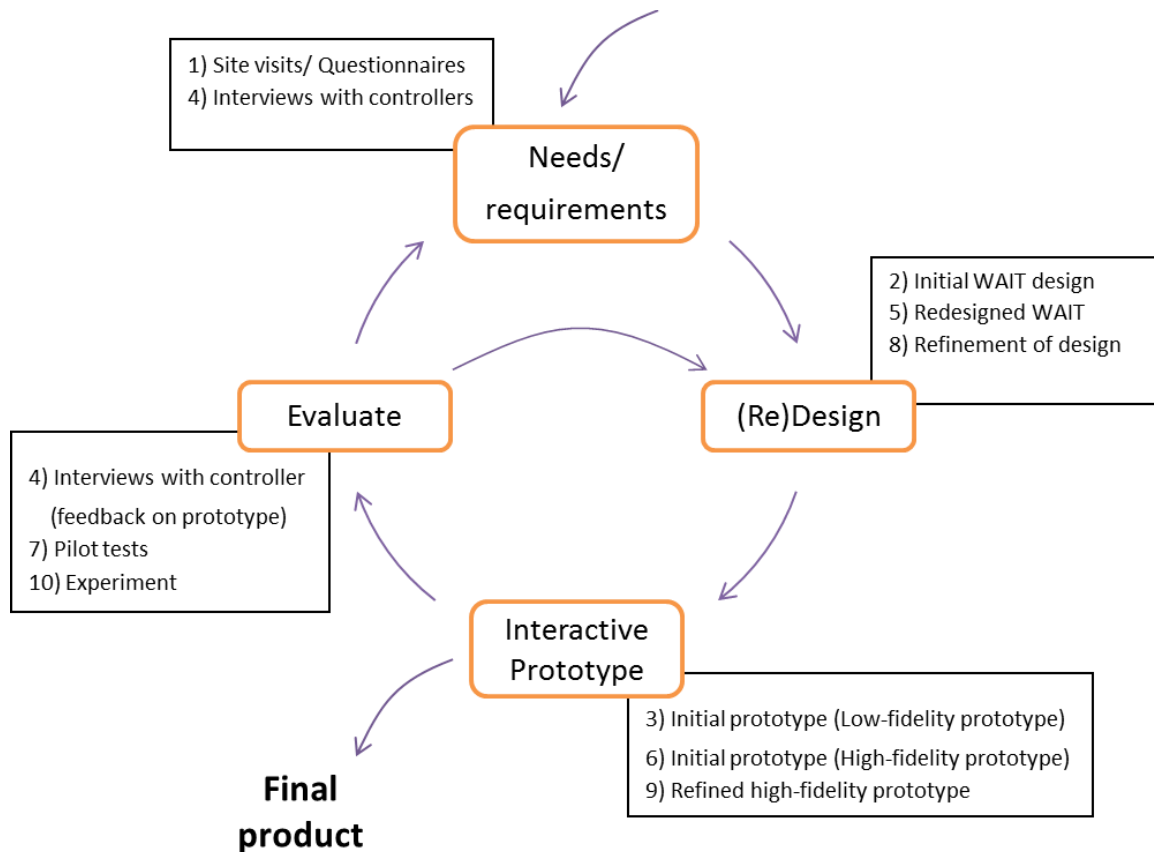


Figure 4.1: Design lifecycle model. Adapted from (Sharp et al., 2007)

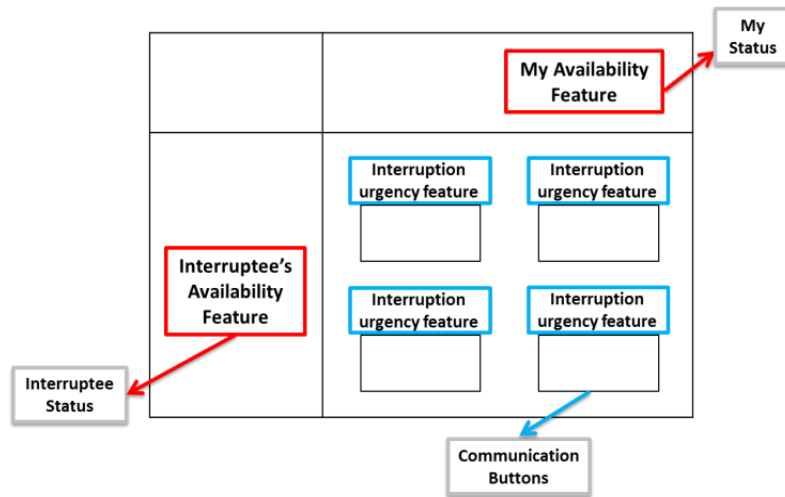
## 4.2 WAIT Prototypes

The standard VSCS interface was used as the starting point. Controller interruption management was enhanced by introducing features providing support for:

- Communicating availability
  - Awareness of another controller’s availability to be interrupted

- Indication of one's own availability
- Communicating urgency level of an interruption
  - Awareness of an incoming call's urgency
  - Indication of the urgency of an outgoing call

Figure 4.2 shows a redesigned high-level layout of a controller's VSCS screen with the approximate positions of the new features. The tool feature's terminology is reflected in Figure 4.2.



**Figure 4.2: Key features within WAIT, a redesigned VSCS interface**

The intent of the design was to provide a test-bed where new interruption management concepts could be tested. As such, the current design is not optimized; it is not intended to appear exactly the same as what would be expected in a production environment (for example, it is immediately obvious that screen space is left unused). The top right corner of the WAIT interface in Figure 4.3 is reserved for a controller to specify his/her own availability. The left hand side is reserved for displaying the availability of a controller he/she is attempting to contact; it appears only when requested. The bottom



right of Figure 4.1 shows buttons, envisioned as similar to these on standard VSCS screens and modified to provide a means of conveying and observing the urgency of an interruption.

The following sections describe in more detail potential ways of implementing the availability and urgency level of an interruption.

#### **4.2.1 “Availability” Prototypes**

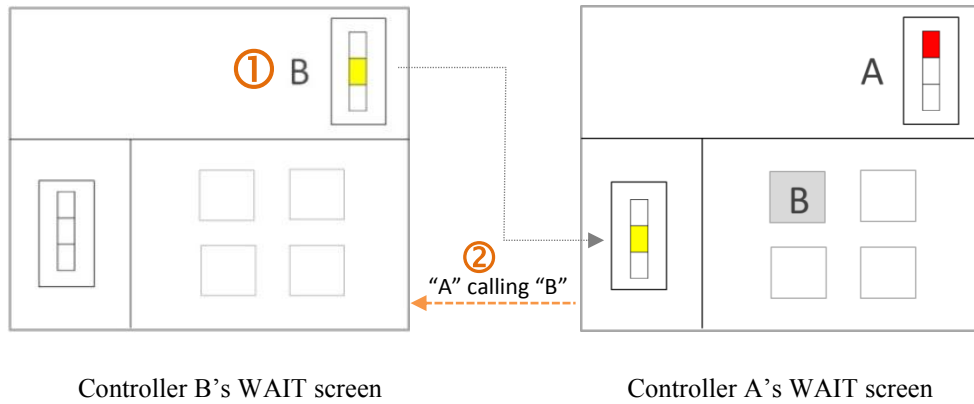
Three design prototypes for supporting an availability feature were generated: controller-specified status levels, controller-specified acceptable interruption activities, and controller- automatic status levels. In all cases, a controller calling to interrupt would be shown the “availability” of the controller being called on the left side of the caller’s VSCS screen.

##### **4.2.1.1 Controller-Specified Status Levels**

The availability feature in this prototype is represented by three-color availability button levels. Notionally, red would indicate a preference to be interrupted for only matters of the most extreme urgency, yellow for matters of operational necessity, and green for nominal conditions. The left side of Figure 4.3 illustrates the first prototype where controller B has assigned her availability manually using one of three colored buttons (Yellow). The right side of Figure 4.3 shows how this would be reflected in controller A’s screen when he initiated a call to controller B: the availability of B appears on the left side of A’s screen as “Yellow”. Also visible in the top right of controller A’s screen is the red button reflecting the availability that he has set for himself.

Controllers in this prototype would set their status based on their personal judgment of availability. Factors such as personal busyness or weather or emergencies are examples of why controllers would change their availability. Once the controllers find that they become more or less available, they

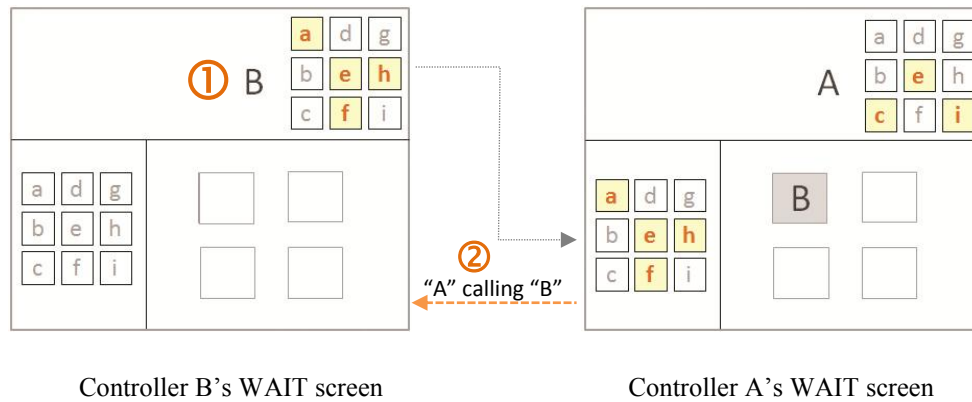
would change it to the status that reflects their new availability. For instance, if a controller set her availability as Yellow (as in the left side of Figure 4.3) then felt more comfortable accepting more mundane tasks, she would shift her availability from Yellow to Green.



**Figure 4.3: Controller specified availability levels**

#### 4.2.1.2 Controller-Specified Acceptable Interruption Activities

Figure 4.4 introduces a second prototype where the availability is specified through individual buttons identifying activities that are accepted or approved as topics of communication (e.g. handoffs, weather requests, etc.). Due to screen real-estate challenges, this would require either a very limited set of activities or a mapping of activities to short-cut labels on the buttons. The left side of Figure 4.4 shows that controller B is willing to receive interruptions about ‘a’, ‘e’, ‘h’, and ‘f’ type of interruptions, assuming that ‘a’ could stand for “interruptions about weather reports,” and ‘h’ could stand for “handoffs” etc. The right side of Figure 4.4 presents how this would be reflected in controller A’s screen when he initiates a call to controller B. Also visible in the top right corner of controller A’s screen is ‘c’, ‘e’, and ‘i’ type of acceptable interruptions which reflects the availability that he has set for himself.



**Figure 4.4: Controller-specified acceptable interruption activities**

Once controller B finds that she is not able to receive interruptions about (h: handoffs) but willing to receive interruptions about (d: “Point Outs”), she would change her status to ‘a’, ‘d’, ‘e’, and ‘f’ instead of ‘a’, ‘e’, ‘h’, and ‘f’ (FAA, 2013a).

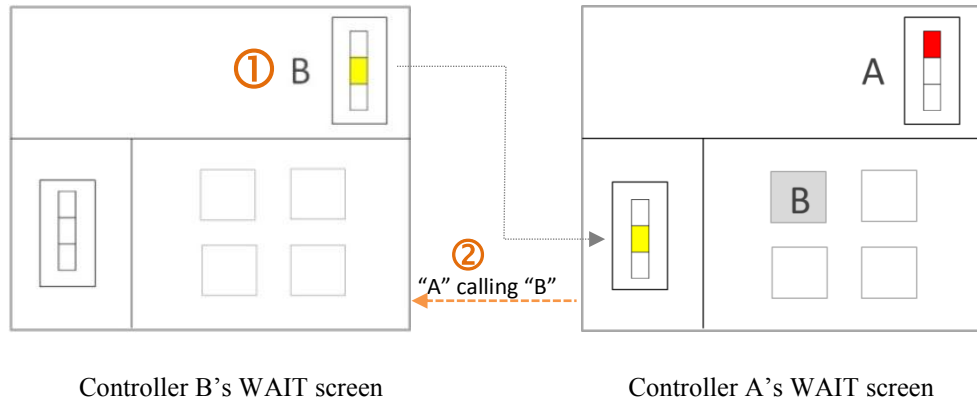
#### 4.2.1.3 Controller-Automatic Status Levels

In contrast to the first two prototypes that rely on the controller to assign his/her status, Figure 4.5 depicts a third prototype that captures the case in which a controller’s availability is set automatically through software monitoring relevant operational states. As an initial prototype, the state is represented by the number of aircraft under the control of a controller, though more sophisticated metrics, such as dynamic density, could also be used (Kopardekar et al., 2008). The availability would be shown in the same space as in the previous two prototypes (Figure 4.3 and Figure 4.4), and its appearance is similar to prototype 1 (colored buttons). However, in this prototype, each color level is tied to a range of the number of aircraft under control.

The ranges would likely differ between different sectors, so the ranges would need to be defined offline by controllers or technical support staff. For example, in one sector a “Red” level would mean

that the controller is handling more than 20 aircraft; a “Yellow” level would mean that the controller is handling a range of 10-20 aircraft; finally, “Green” would be handling less than 10 aircraft. While in another sector, a “Red” level would mean that the controller is handling more than 10 aircraft; a “Yellow” level would mean that the controller is handling a range of 5-10 aircraft; finally, “Green” would be handling less than 5 aircraft. The ranges would reflect sector characteristics such as perceived complexity, average number of aircraft, and other measures of the difficulty of a sector (Laudeman et al., 1998; Smith et al., 1998). It would also be possible to consider the experience level of the controller working the sector and have the ranges adapted to reflect whether a new trainee is present (much lower traffic levels required to reach “Red” level) or whether an experienced veteran is present (much higher traffic levels required to reach “Red” level).

In this way, the colours would be operationally relevant to the controllers, but by being determined automatically, would not impose any additional tasks or actions upon the controller. As conditions vary, with the number of aircraft being controlled increasing, the availability to be interrupted would automatically decrease; similarly, as the situation being controlled becomes less complex, the availability would automatically increase without controller intervention. Within the automatic setting of availability, controllers should also have the ability to manually override the automatically determined state as required.



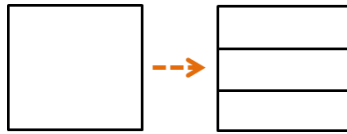
**Figure 4.5: Controller-automatic status levels**

## 4.2.2 “Urgency Level” Prototypes

In addition to the availability features, several means of communicating the urgency level of an interruption have been developed. Prototypes have been developed for the ability to set the urgency level of an interruption by the controller initiating communications and to show the urgency level of an interruption to the controller receiving the communications.

### 4.2.2.1 Setting the Urgency Level of an Outgoing Call

Given the restricted space available, a single prototype was developed to allow controllers to set the urgency level of an outgoing call. In order to communicate the urgency level of an outgoing call, the standard button area was subdivided to provide three additional buttons corresponding to low, medium, and high urgency level (Figure 4.6). Similar to current interaction with the VSCS, to initiate a call, a controller would touch the subdivision corresponding to the urgency level. This action would prompt the receiving-controller’s availability to be shown in the left side of the calling-controller’s screen, affording them the opportunity to cancel the call if deemed appropriate.

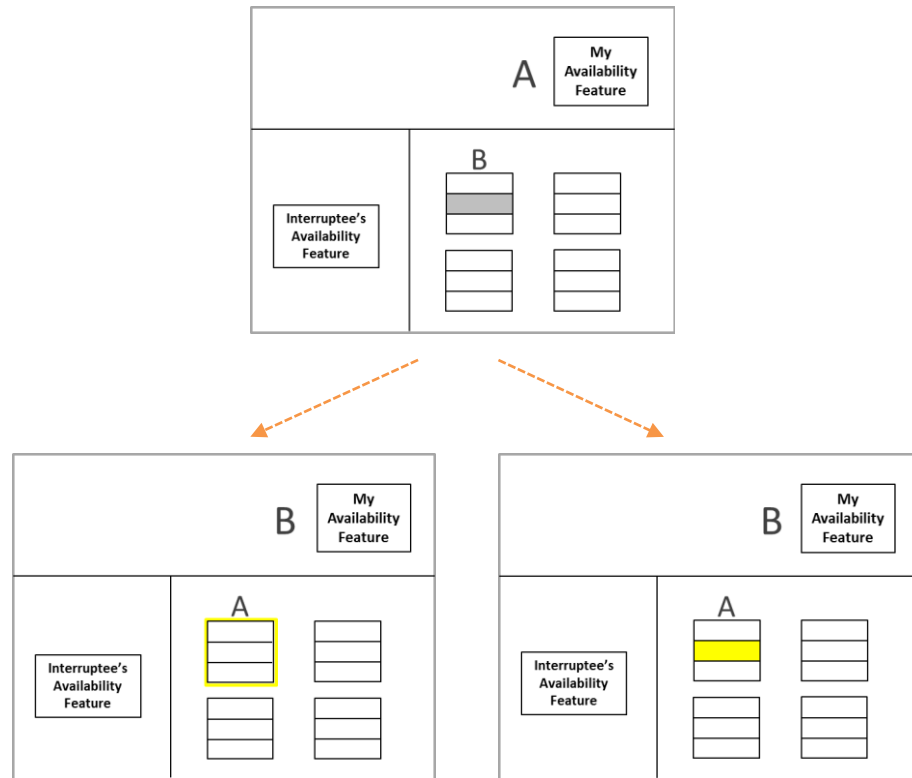


**Figure 4.6: Existing VSCS Button modified with urgency level levels.**

#### 4.2.2.2 Showing the Urgency Level of an Incoming Call

Two potential designs have been developed for showing the urgency level of an incoming call. In both cases, the urgency level of an incoming interruption is shown by modifying the standard button area corresponding to the controller that the call is coming from. In addition, both cases use the same color coding scheme to specify urgency level, coded with green, yellow, and red, respectively.

Figure 4.7 shows the case of an outgoing call where controller A is calling controller B. The top row of the figure shows controller A's WAIT screen, while the bottom row shows the two prototype implementations of an urgency level display. The first prototype is shown in the bottom left of Figure 4.7. It uses color coding on the border of the button for the controller that is calling (Controller A); the color corresponds to the assigned urgency level as described above. The second prototype, shown in the bottom right side of Figure 4.7, lights up the assigned urgency level button within the area reserved for communicating with controller A. In both cases, the receiving controller (controller B) can accept the calls using the normal practicing of touching the screen.



**Figure 4.7: Two methods of showing urgency level of an interruption to controller B coming from controller A**

### 4.2.3 Summary

The implementation of the availability and urgency level features in the prototypes were developed based on the data collected from field observations and questionnaires that were discussed in the previous chapter. The next section describes how the prototypes were evaluated through interviews and a Participatory Design process based on non-interactive low-fidelity versions of the prototypes.

## 4.3 Prototype Evaluations

### 4.3.1 Method

The prototypes presented in the previous section attempt to integrate interruption management support into an existing operational tool. While several obvious advantages and disadvantages could be identified for each, it was important to obtain subject-matter expert feedback on the general notions and on operational feasibility and usefulness. In order to collect this feedback, semi-structured interviews were conducted using both Cognitive Task Analysis (CTA) and Participatory Design (PD) methods. Both methods were used in a session with active and retired controllers. Each session took approximately two hours and was conducted over the phone while simultaneously using an online meeting application (Mikogo, [www.mikogo.com](http://www.mikogo.com)) to share and manipulate the presentation of the prototypes. The study sessions were recorded for the later purpose of clarification and review.

#### 4.3.1.1 Cognitive Task Analysis

Cognitive Task Analysis (CTA) studies the cognitive behavior that underlies an accomplished work without regard to whether the work was successfully completed or not. It also distinguishes between experts and novices in their acquired knowledge related to a task performance, especially when dealing with non-routine incidents which are more likely to be handled more efficiently by experts (Crandall et al., 2006). CTA includes several main aspects. An important aspect is Knowledge Elicitation, which can be described as “a set of method[s] used to obtain information about what people know and how they know it: the judgments, strategies, knowledge, and skills that underlie performance” (Crandall et al., 2006).



The CTA section of the interview was an example of Knowledge Elicitation. In order to further the understanding of the operational environment and interruptions, questions were asked about how the VSCS is currently used, as well as the controllers' perceptions and experiences on the need for interruption management. Additional questions probed the communication needs of controllers and the differences in the means of communications. Also included were questions that focused on critical incident reviews of situations when low or high urgency level interruptions had operational impacts. As well, questions probed the features of the existing VSCS screen, the cues the screen provides to the controllers, and the strategies and sources of information used to predict the busyness statuses of other controllers.

#### 4.3.1.2 Participatory Design

There are many approaches that have been developed to help engineers design products in a way that meets user needs. One of these approaches is called Participatory Design (PD). In PD, developers, designers, practitioners, and end users participate in the design process of a product in order to address the users' needs (Simonsen et al., 2013). PD is performed through discussions with the involved users about their thoughts, suggestions, or ideas for improvement or new directions, working together on wireframes/prototypes/mockups of the system or tool design expected features. Working on prototypes gives the benefit of flexible and simple user testing and helps designers narrow down their design ideas in a low time/cost manner.

In the PD section of the interview, participants were presented with the prototypes described above. For each prototype they were asked to critically evaluate its strengths and weaknesses. The PD questions were used to gain insight into the design acceptability, feasibility, as well as operational considerations that might only be known to end users. Insights were also gained to identify issues

generated by the designs and other relevant interruption management problems that were not addressed by the designs. Furthermore, participants were asked for other ways to support each feature. The prototype design ideas were shown to participants through a PowerPoint presentation illustrating the different design features and were shared through the online meeting application Mikogo.

### **4.3.2 Participants**

Retired or active air traffic controllers were recruited to participate in this study. In order to participate, controllers were required to have experience working in ATC towers as ground or air controllers or in ATC centers as radar controllers. Participation was voluntary and the controller participants were not remunerated for their involvement. Three male controllers participated in the study. Two of them were actively working in ATC facilities, and the third was a retired controller. Each had worked at a range of facilities and sector types in North America, and had a minimum of ten years of experience as a controller. All the controllers are from North America.

### **4.3.3 Results**

Substantial data and insights were generated from the six hours of interviews with the interviewees. In general, participants endorsed the potential of such a tool because of its potential to reduce the chances of engaging in an unwanted conversation. To illustrate, if pressing a button can eliminate the seconds needed to engage in an unwanted, distracting, and/or a low priority conversation, no matter how operationally relevant, it would be very helpful. Interviewees also reported that the proposed tool would assist with learning how to manage incoming interruptions and how to judge when to interrupt another controller, which are both critical steps in a controller's training.

Interviewees also identified several general reservations and challenges that would need to be overcome. They were very concerned about any implementations that added additional steps to the communication process; assisting in awareness was valued but not at the expense of making it more difficult to initiate time-critical communications. As well, while the interviewees supported the idea of showing their availability with their colleagues, they were concerned about the potential for abuse, such as controllers consistently maintaining a ‘do not interrupt’ status for non-operational reasons. Interviewees also pointed out that in some cases, the number of communications links (e.g., required buttons on the VSCS) is very large, severely restricting screen space; the space needed for the interruption management features was seen as a drawback for those situations.

Finally, the interviews showed that there are important operational differences in the types of communication links between controllers. Different terminology is used in different facilities, but controllers drew a distinction between “shout lines,” “hot lines,” and “dial lines.” For shout lines and hot lines, pressing a button on the VSCS screen creates an immediate “headset-to-headset” connection between controllers. This provides a caller with awareness of the availability of the receiving controller based on overhearing conversations (with pilots or other controllers) the receiving controller is engaged in. With dial lines, pressing a button on the VSCS screen initiates the equivalent of a telephone call to the receiving controller, necessitating an action on behalf of the receiving controller to accept the call. These differences imply that an interruption management tool needs to have the flexibility to handle these very different types of interruptions.

The following subsections describe highlights of the feedback on the specific prototypes.

#### 4.3.3.1 Availability Prototype Evaluation

##### ***Prototype 1: Controller-specified status levels***

There was a range of opinions on the feasibility of Prototype 1 (see Figure 4.3). Participants generally understood the intended meaning of the colored buttons and felt that the feature would help them to determine when to interrupt another controller. For example, one participant recommended continuing development of the feature saying, “It would save the extra time it takes to engage in a conversation [...]. It looks very useful, simple, quick, easy, and fairly intuitive especially for young trainees.” However, there was a range of opinions as to which colors should be present. One participant suggested that the yellow color (middle status level) should be eliminated because availability should be a binary choice: either a controller can accept an interruption or they cannot. Another participant suggested an alternative interpretation process: the availability status button could be used by the receiving controller to communicate a status back to the caller without having to speak:

*Green: I can answer you*

*Yellow: I can't answer right now, but don't hang up - I'll get to you momentarily*

*Red: hang up - I'll call you back when I can*

This is a unique functionality that will be considered in future work.

##### ***Prototype 2: Controller-specified acceptable interruption activities***

For this prototype (see Figure 4.4), the participants universally rejected the practicality of having to specify the acceptability of individual actions. Reasons specified included excessive time spent on managing the tool, additional training time, and the lack of a quick ‘at-a-glance’ depiction of availability. In addition, interviewees stated that the large diversity of operational situations and

procedures would make it difficult to have a consistent assignment of activities to buttons. One controller suggested as a modification to this feature representation is creating buttons that inform interrupters about the tasks that the controller interruptee cannot receive at that moment. To illustrate, assuming that the button “d” means “Point Outs,” if the controller set his/her availability as ‘d,’ it means that he/she is not able to receive interruptions about “Point Outs.” However, in times of extreme busyness, it would be very difficult for a controller to spend time on specifying which interruption topics cannot be operated. Based on the feedback, this prototype is no longer being pursued.

### ***Prototype 3: Controller-automatic status levels***

With respect to Prototype 3, interviewees responded favorably to the use of automation to decrease the workload of managing the tool; however, concerns were raised about using the number of aircraft as the indicator of a controller’s availability. Consistent with previous work on complexity metrics, participants reported that the absolute number of aircraft could be misleading due to variations between the number of aircraft handled by each sector, differences in operational procedures, weather conditions, and the experience of the controller. This would be particularly acute if the interrupters were not knowledgeable about the sector they were calling. Participants identified alternatives, including using the number of aircrafts as a percentage of a sector’s Monitor Alert Parameter (MAP) which is “an indicator of a capacity limit for each sector of airspace. [...] In other words, MAP values are set to reflect controllers’ acceptable workload” (Kopardekar et al., 2008). Participants also stated that consideration should be given to using averaged values of operated aircraft over a period of time in contrast to an instantaneous indicator.

#### 4.3.3.2 The Urgency Level of an Interruption

Participants had mixed responses to the techniques for setting and observing the urgency level of an interruption (see Figure 4.7); however, their feedback on the variation of the urgency level representation was similar. The most considerable concerns were about the potential for additional workload if an extra step was required, and whether it was appropriate for “shout line” and “hot line” connections (where the controllers are instantly connected “headset-to-headset”) so that they will not spend time to visualize the urgency level indicated in the call. Participants did feel it would be useful to be able to know the urgency level of an incoming call, however there were concerns that the calling controller might not understand the reasons a call is not answered. While this can also happen in current operations, the lack of an answer to a “high urgency” call might be very confusing.

An additional concern was raised with respect to controller’s comprehending the meaning of the urgency levels. For example, if a call is sent with a “Green” urgency, the controller being interrupted might continuously delay answering it, knowing that it is not urgent to be answered; this in turn might cause the interrupter to raise the urgency level in order to force the interruptee to answer. There was also a concern about controllers having inconsistent standards for each level of urgency. Priorities are different between controllers and sectors, issues that are important to the interrupter might not necessarily be important to the controller being interrupted. As a further simplification, participants suggested that it would be better to represent the urgency of an interruption by one message only. This would demonstrate an emergency situation instead of three different levels because when controllers are very busy, all they need to know is if the call is about an emergency or not.

#### 4.3.3.3 Other Suggestions Made by Controller Participants

There were several additional general suggestions made by the participants. One participant suggested showing availability as an indicator that lights up when a controller is using any of their communication channels (e.g. radio to pilot, a dial/shout/hot line to another controller) as this is a commonly used and understood way of judging if the controller is very busy. Also, it was explained that when controllers get really busy, it is beneficial to have the availability indicator goes back to the default status automatically after a certain time because if the developed tool was implemented, it would become a second nature for the controller to set the availability level; however it would not be a second nature to turn it back to the default status.

Furthermore, one controller suggested that rather than showing an urgency level of an interruption, it would be more useful if the receiver knew what the interruption was about. For example, making each button subdivision means a certain interruption task, such as emergency, would help the interruptee re-prioritize the tasks at hand.

#### 4.3.4 Implications for Further Prototype Development

Based on the feedback gained through the interview sessions with the air traffic controllers, the WAIT awareness features for showing a controller's availability and the urgency level of an interruption were prioritized and refined for further development. Prototype 1 and 3 of controllers' availability feature were selected to represent controllers' availability in different case studies. The first availability representation allows the controller to set his/her availability based on the personal evaluation of availability as unavailable, possibly available, and available. The second one is automatically set by the number of aircraft a controller is handling. Moreover, in both cases, the availability levels will have three colored levels of red, yellow, and green that will differ in meaning

based on the case it is representing. On the other hand, the urgency level was decided to be represented by two button subdivisions instead of three. Each level communicates an urgency level; the top level is “urgent” and the bottom one is “non-urgent.” Colors were excluded from this feature except for highlighting the subdivision to show that a call is initiated or active in order to reduce any distraction or interference effect of the other colors on the WAIT screen.

#### **4.4 Summary**

In summary, several WAIT prototypes for better supporting interruption management in active air traffic control applications: three availability feature prototypes (controller-specified status levels, controller-specified acceptable interruption activities, and controller-automatic status levels) were designed in addition to two prototypes that show different graphical ways of presenting the urgency level feature. Three subject-matter experts were interviewed through CTA sessions to elicit additional information about interruptions and communications between controllers; they also participated in Participatory Design sessions to get subject-matter expert insights about each prototype. Initial feedback suggested that the designs are addressing a noteworthy operational problem, but there are a number of operational constraints that need addressing. Enhancing availability features through simplified status indicators and/or automated means were identified as the most promising developments. Also, reducing the number of levels set for communicating the urgency level of an interruption call was identified as much easier and understandable to the interruptees. Based on the initial feedback, a part-task simulation environment was created to further study the effectiveness of both features in a controlled environment.



## Chapter 5

### Experimental Platform and Design of the Experiment Evaluation

Developing systems for complex, dynamic environments is a critical process that requires accurate work and vision. Changes should not be implemented in working systems without extensive testing, evaluation, and assessment of safety and efficiency implications. Testing the WAIT tool in real ATC environments would be extremely difficult, if not impossible, because of the serious negative consequences if a bug or an error occurred during the system's deployment. Therefore, due to the previous reasons and the dynamic nature of the ATC information, an initial evaluation of the WAIT tool was developed using a human-in-the-loop part-task experiment in the laboratory to evaluate its effectiveness in a safe manner.

This chapter describes the design of a study and the experimental platform used to evaluate the refined WAIT prototype. An overview of the developed tool and its different interfaces and an overview of the experimental environment are presented. In addition, the second section provides a detailed explanation of the design of experiment. Finally, modifications that were required during the experiment design development phase are described.

#### 5.1 Experimental Design

##### 5.1.1 Experiment Objectives

As discussed in Chapter 1, the third objective of the thesis is to evaluate the refined versions of WAIT. Two different WAIT interfaces are evaluated using user-based experimental methodology and

then a comparison was carried out between these WAIT interfaces and the Control interface.

Therefore, participants interacted with three different interfaces.

There were three objectives of the experiment:

- 1) Assess whether the presence of interruption management tools helps or hinders participant performance.
- 2) Determine which version of the WAIT availability feature is preferred by participants.
- 3) Assess the acceptability of the WAIT urgency feature.

These objectives are described in more detail below.

#### 5.1.1.1 Interruption Management Tools and Performance

The primary objective of the experiment was to assess whether the introduction of interruption management tools had a positive or negative impact on participant performance and perception of the tools. The goal was to compare a Control condition, or interface representative of current operations with no availability and urgency features, with conditions where interruption management tools are present. Assessing the impact on performance gives an indication of whether the development of such tools has potential and provides an opportunity for real-time, hands-on feedback on the operational acceptability of introducing tools in an environment representative of the ATC task.

#### 5.1.1.2 Availability Feature

As mentioned in Chapter 1, the research question was aimed at investigating techniques that communicate controllers' availability. This comprises exploring whether the presence of any availability features is desired and provide improvement in interruption management, and which variant of availability feature is preferred. Consequently, the availability feature is designed to provide participants with the situation awareness of the availability of other controllers to be

interrupted; this is hypothesized to allow for better timing of calls to those controllers and hence to reduce the negative impact that may be caused by interruptions. The feature can also make other controllers aware of the participant controller's availability, reducing the probability of a less relevant incoming call happening at an inopportune moment.

#### **5.1.1.3 Urgency Level Feature**

Similarly, the second part of the research question was to investigate whether providing the urgency level of calls would help in interruption management. Therefore, this feature is designed to help participants become aware of the urgency level of incoming calls. This can help them reprioritize the tasks at hand and provide an initial assessment regarding the call. Consequently, any inconvenience caused by interruptions would be reduced. Also, this feature enables the participants to specify the urgency level of the outgoing calls to make the controller interruptee aware of the urgency level of the call. This would change the response behavior of the recipient controller.

#### **5.1.2 Experiment Conditions**

In order to meet these objectives, the experiment was designed with two independent variables reflecting the presence or absence of the availability and urgency features. The three availability conditions were: no-availability in the control screen (Control), manual setting of availability, and automated setting of availability. The urgency level conditions were: not provided (Control) or provided (through a two level urgency button). A fully crossed experimental design to evaluate all of the WAIT features individually would require a 3 (availability condition) x 2 (urgency level condition) experimental design.

For practical reasons, primarily the length of time required for a complete within-subjects design, it was decided not to implement a fully crossed model and to focus on the three cases that would provide the most insight into the research questions. These three cases are highlighted with the thick borders and check marks in Table 5.1. This decision was also influenced by a perceived need to prevent participants from the effects of fatigue or boredom, which could degrade their performance. This is especially given the need for individual training sessions on each experimental condition.

**Table 5.1: Full design experimental conditions**

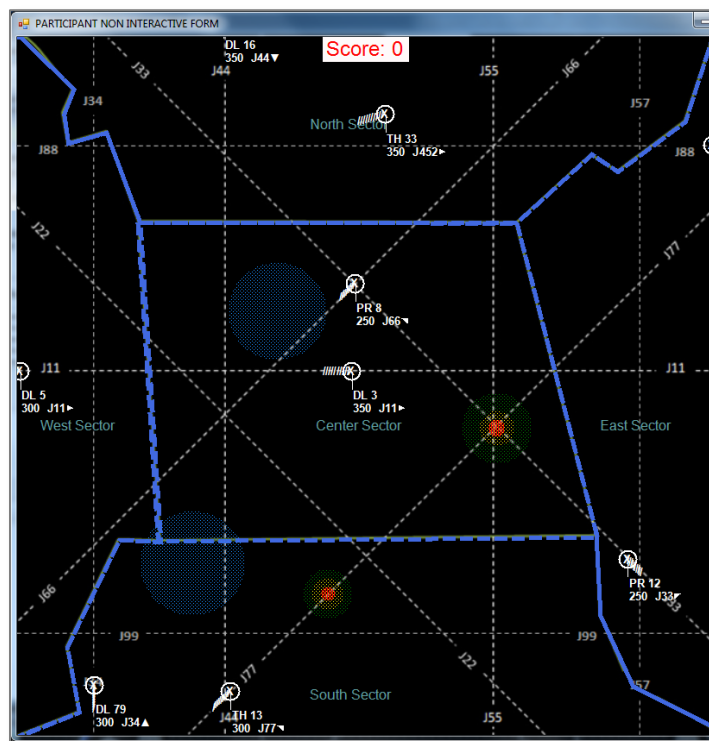
	No availability	Manual Availability	Automated Availability
No urgency level	✓ (“Control”)	X	X
With Urgency level	X	✓ (“Manual”)	✓ (“Automated”)

The experiment design for the three selected conditions was a repeated measures design; each participant saw every condition. To combat any order effect (learning effects), the experimental cases were alternated as explained in sub-section 5.1.5.1. For clarity in presenting the results, the three conditions have been labeled Control, Manual, and Automated.

### 5.1.3 Task

The task requires participants to send and receive calls to/from controllers of other sectors and to pilots. The goal is to capture the essence of the collaboration between controllers in real ATC environments while still making the task simple enough to be performed without ATC training. Furthermore, participants are tasked with controlling the flow of in/outbound aircraft within the

assigned Center Sector (see Figure 5.1). Their job is to safely guide aircraft through their airspace as safely and efficiently as possible; no procedures had to be met by the participant beyond intent for aircraft to exit along the assigned line. They should work on preventing aircraft from colliding with each other or from passing through regions of critical weather conditions by communicating with other controllers or pilots. This emulated some of the key features of the air traffic control task; they were selected based on the likelihood of creating the need for controllers to communicate with each other.



**Figure 5.1: Center sector in the radar screen**

In addition, participants are instructed to give control instructions verbally to ensure safe aircraft movements throughout their sector until it reaches its planned destination. Also, they are asked to

communicate with other controllers or other pilots for aircraft control requests. Participants can obtain or provide information about other sectors or aircraft moving in the other sectors by calling other sector controllers. These calls may involve control tasks such as rerouting aircraft to prevent potential collisions or to prevent contact with storms or turbulence, or they may introduce tasks, such as collecting or providing information. Similarly, participants communicate with pilots for the same reasons, but only about aircraft within the “Center Sector.”

During the data collection sessions, both pilots and other controllers (represented by the experiment team) make calls to the participant. Participants are instructed to prioritize their tasks at hand when receiving the calls.

#### **5.1.4 Scenario Design**

The lack of expert participants, as well as the limited time available for each experimental session, affected the type of scenarios used in the experiment. Creating appropriate scenarios that emulate the complex types of interruptions in the ATC environment, yet are able to be applied in the short ten minute data collection sessions, was a challenge. It was important to ensure that differences seen in several data collection sessions reflect the different communication Control/WAIT prototypes, and are not due to other unintended effects such as learning, fatigue, and/or familiarity with the sequence of events that will occur. Of particular concern was ensuring that the underlying traffic problems are similar enough that any differences seen can be attributed to the different communication prototypes, but different enough that participants do not ‘recognize’ what is coming in the second and third data collection session.

In the current experiment, scenarios were constructed by assuring that they all have a similar number of interruptions, communication timing, and aircraft traffic. In other words, they were created to have

similar workload demands. This was done by utilizing a specific technique to generate multiple traffic configurations that would appear unique to the participant, but which had fundamentally similar characteristics.

This was achieved by varying the initial configuration of aircraft in a symmetrical way. The first scenario was created based on the sector map and a series of flight paths that would produce a desired number of potential collisions without overwhelming a participant. The second and third scenarios were created by rotating the traffic routes first horizontally (for the second scenario) and then vertically (for the third scenario) and then rotating initial aircraft positions so they started on the resulting traffic routes.

In addition, a special program coding was used to generate new aircraft call-signs and flight numbers. The program worked by inserting into it values from an existing scenario then inserting three specific values: all the possible airline call signs used, a “Rotate” number that is used by the program to generate new airline call signs, and an “offset” number that controls the generation of new flight data. For example, if we already have a scenario that consists of three aircraft DL 10, TH 20, and PR 30, the list of airlines that should be entered into this program is DL, TH, and PR. The Rotate number should be between 1 and the number of available airlines-1; in this example, the “Rotate” number is 2, and the Offset value was given the value of 5 as shown below in Figure 5.2.

<b>List of Airlines</b>	DL	<b>Rotate</b>	<b>Offset</b>
	TH		
	PR		
		2	5

**Figure 5.2: Example of scenario generation data requirements**

With those values entered, the airlines code will rotate by 2, so DL becomes PR, TH becomes DL, and PR becomes TH, and each of the flight number will be added 5. Therefore, the new set of airlines (DL 10, TH 20, and PR 30) in this sample scenario is (PR 15, DL 25, and TH 35).

This common underlying traffic configuration allowed scripts for pilot and other controller requests to be standardized across the three scenarios, while the appearance of aircraft appeared novel for the participants.

### **5.1.5 Procedure**

A recruitment email was sent to a UW graduate e-mail group and to personal contacts (See Appendix B for Recruitment Email). The individuals who were interested in participating in the study signed-up through a tool (Doodle.com) booking webpage. After that, those individuals were sent documents including an information letter that they were asked to review prior to their assigned date (see Appendix C) and an informed consent form (see Appendix D) to sign when they attend the study. Additionally, they were given a link to an online demographic questionnaire and were asked to fill it out (see Appendix E). All of these tasks were required to be performed ahead of time in order to speed up the pre-experimental tasks. On the experiment date, participants come to the experiment room, and before beginning the experiment, they sign a hard copy of the consent form.



The experiment consists of an approximate two hour session in which the participants complete a general training session, followed by three data collection trials accompanied with three specific training sessions (as described in a following sub-section 5.1.5.2). In each data collection session, the communication screen is configured and remains in Control, Manual, or Automated interface condition. The order in which participants experience the different conditions of the Control/WAIT tool is randomized across the data collection sessions in order to minimize learning effects. Upon the completion of each 10 minute trial, the participants spend about 5-10 minutes answering an online post-trial questionnaire to evaluate their experience in that trial. The post-trial questionnaire was the same for all the trials (see Appendix F). When the three trials are completed, participants took part in an overall questionnaire to elicit their insights as a whole after experiencing the different representations of WAIT features (see Appendix G), followed by a 10-15 minute interview session in order to gather feedback about the interfaces and the task scenario (see Appendix H). Both the trials and the interview sessions were audio/video recorded for further analysis.

#### 5.1.5.1 Experiment Trials

The experiment used the “availability” factor to compare the performance of participants in the three different interface conditions. A second factor, urgency level, was also designed into the experiment, varying between being presented in the Manual and Automated conditions, and absent in the Control condition. Due to the limits of time resources, a full cross experiment design could not be used.

As mentioned previously, the experiment was divided into three blocks, one for each of the experimental conditions. To eliminate the learning effects from the participants, the order of the condition blocks was not the same for all participants. It was based on all possible arrangements of the three conditions (Table 5.2)

**Table 5.2: The trial packages**

<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>
Control	Control	Manual	Manual	Automated	Automated
Manual	Automated	Control	Automated	Control	Manual
Automated	Manual	Automated	Control	Manual	Control

Similarly, the three aircraft scenarios that were created for the experiment (scenario 1, scenario 2, and scenario 3) were ordered randomly using an automatic dice application (Table 5.3).

**Table 5.3: The scenario packages**

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>	<b>F</b>	<b>G</b>	<b>H</b>	<b>I</b>	<b>J</b>	<b>K</b>	<b>L</b>
3	2	1	1	2	3	2	1	1	2	1	3
2	3	3	3	1	2	1	2	2	1	2	2
1	1	2	2	3	1	3	3	3	3	3	1

Since it was planned to initially run the experiment on twelve participants, a table was created from the product of the trial packages (T1, T2, T3 etc.) and the scenarios packages (A, B, C, etc.) as shown in Table 5.4.

**Table 5.4: The experiment plan for each participant**

<b>Participant #</b>	<b>P1</b>	<b>P2</b>	<b>P3</b>	<b>P4</b>	<b>P5</b>	<b>P6</b>	<b>P7</b>	<b>P8</b>	<b>P9</b>	<b>P10</b>	<b>P11</b>	<b>P12</b>
<b>Trial package #</b>	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
<b>Scenario package #</b>	A	B	C	D	E	F	G	H	I	J	K	L

### 5.1.5.2 Training

An interesting challenge emerged when considering the design of the training for the experiment participants. Given the range of functionalities, and only a single iteration with each version of the tool, a decision was made to conduct training in two distinct types. Each type consists of both reference material and hands-on practice with the tools. The first type is a general training that introduces participants to the experimental task and explains the basic software interfaces and communication protocols. The second type of the training is a condition specific training that focuses on familiarizing participants with the specific implementation of the communication tool (Control/WAIT); it is run prior to each data collection session. Using carefully designed hands-on training instructions, important functionalities of the interfaces were explained, and the participants were asked questions to check their readiness to start the study (see Appendix I for the training instructions). If the participants felt that they needed additional practice, they were allowed to repeat any of the training activities.

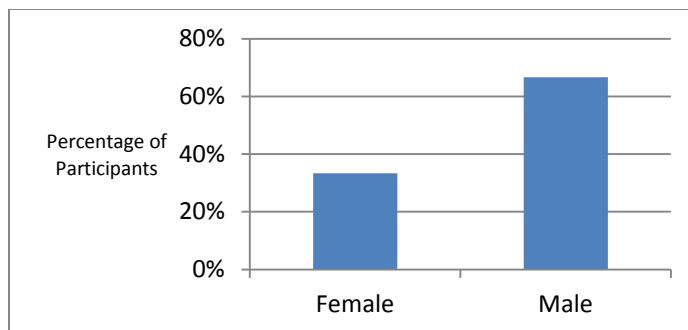
The general training session took approximately 30 minutes. The first 15 minutes of the training was given through a PowerPoint tutorial that describes the purpose and procedures for the experiment and explains the software interface. The tutorial is provided as a reference for participants during the study in a separate monitor. The rest of the time was used to complete a general hands-on mini task scenario in the form of commands that needed to be accomplished and questions that needed to be answered without the experimenter's aid. This part included an example of each task and function of the Control/WAIT and ATC simulation interfaces. In addition, during the hands-on practices, the participant was interrupted and required to interrupt controllers. The purpose of this training was to

expose the participants to all expected situations involved in the control task and to familiarize them with the subtle functionalities of the system.

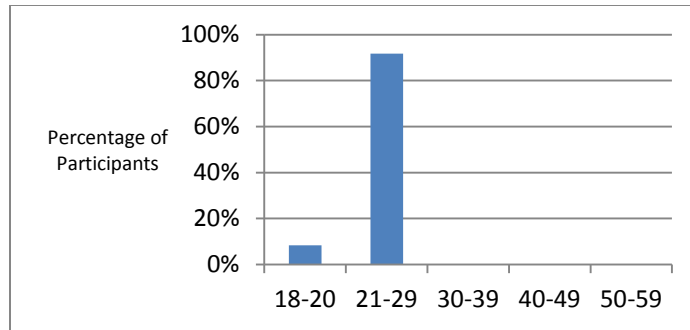
The specific training session required 7-15 minutes and included a PowerPoint tutorial session and a hands-on mini task scenario on the specific functionality related to the following data collection trial (see Appendix J for the whole tutorials). If minimum performance requirements were achieved (when participants were asked a question or instructed to perform a task, and they responded positively), they were advanced to start the study trials.

### 5.1.6 Participants

A total of 16 University of Waterloo participants were recruited. Out of the 16 participants, 12 sets of data were used for the subsequent analysis. Two participant's data were lost due to an experiment software malfunction. The other two's data were removed because of a popped-up error in the software that could not be resolved to continue the experiment. Out of the 12 qualified participants, 8 were males, and 4 were females ranging from 18 to 29 years old (see Figure 5.3 and Figure 5.4).

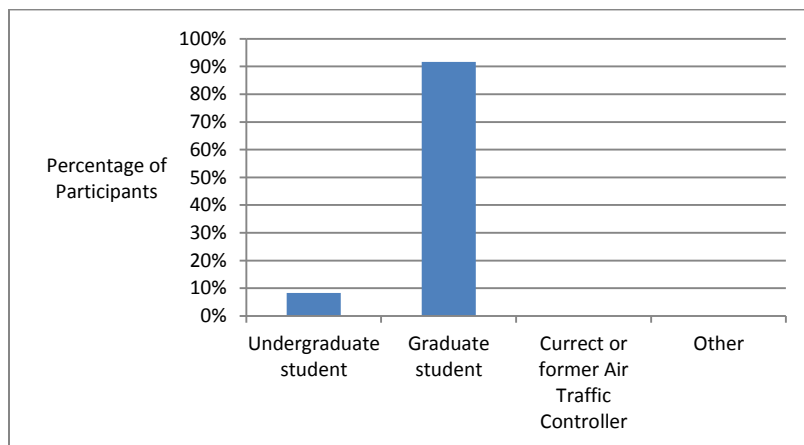


**Figure 5.3: Participants' gender**



**Figure 5.4: Participants' age range**

Moreover, ten participants were graduate students, two were undergraduate students, and none of the participants had any previous ATC training (Figure 5.5). Additionally, all twelve participants had self-reported normal or corrected-to-normal vision and no one was color-blind.



**Figure 5.5: Participants' occupation**

At the end of the study, all of the participants received \$10 as an appreciation for their participation and time commitment. Moreover, participants who joined the study sessions completely or partially were entered into a draw for \$100 gift certificate to a local electronic store. The number of entries depended on the session completion status as well as the accomplished performance score in order to

motivate behavior. For participants who completed the study session, the participants with the five best cumulative scores were given extra entries. For example, the participant with the best score got five extra entries; the participant with the second best score got four extra entries, and so on. The draw took place in the month after the last participant has completed the experiment, and it was conducted using an electronic random draw application (Random.com).

### **5.1.7 Apparatus**

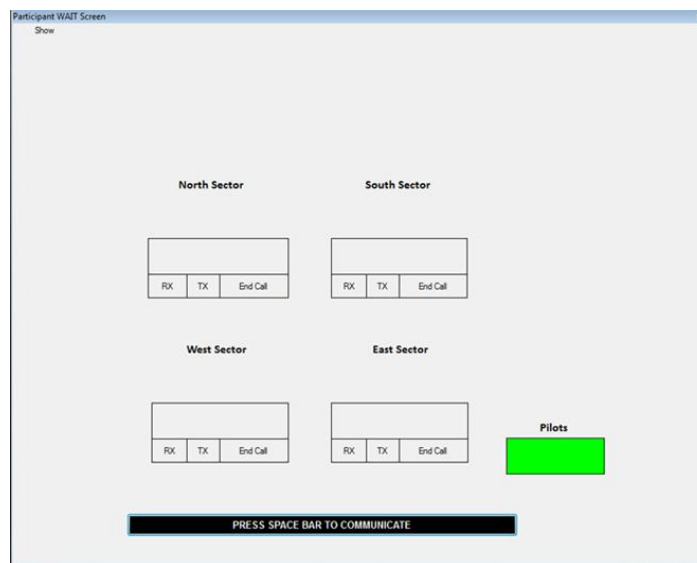
The experiment was conducted using the experimental platform described in the previous sections. The programs were all developed in C# programming language. A Dell server computer in the experiment team room was used to simulate the task Design. The experimental interfaces were developed using the Microsoft C# .NET programming language. Full detailed discussion of the apparatus and software environment is provided in the next section.

## **5.2 Experimental Platform**

The goal of the experiment is to examine how well the developed WAIT communication system helps individuals in managing interruptions effectively. In order to examine the effectiveness of the WAIT, a realistic, but accessible test environment that emulated air traffic control was developed to support the development and evaluation of novel communication and interruption management interface concepts (see also Sasangohar, 2009, p. 38). Developing the WAIT tool and the relevant software required extensive work. The software was tested through intensive pilot tests. Bugs and shortcomings in the original design were identified, and the required modifications were incorporated into the final tools used in the study. This process produced a final version of the tool, interfaces, and training design needed to fulfill the research objective of emulating the key features of the ATC environment without being overwhelming for the participants.

## 5.2.1 Overview of the Control/WAIT Tool

In order to test the difference between the different ways the WAIT tool could support interruption awareness, performance was measured among three variants of interfaces. These variants simulated the controllers VSCS communication screen, and they can be categorized into two main cases. First is the “Control” display. It was simplified for experimental purposes but has most of the functions of the original VSCS without incorporating any new interruption management features (Figure 5.6). It has four controller channels that allow the participant to communicate with other controllers in the experiment world and another channel to communicate with aircraft pilots.



**Figure 5.6: Control interface**

The second case includes the two WAIT displays that have interruption management features (availability and call urgency features). As mentioned in the previous chapter, the two different interfaces of WAIT, the “Manual” interface and “Automated” interface, reflect different ways of

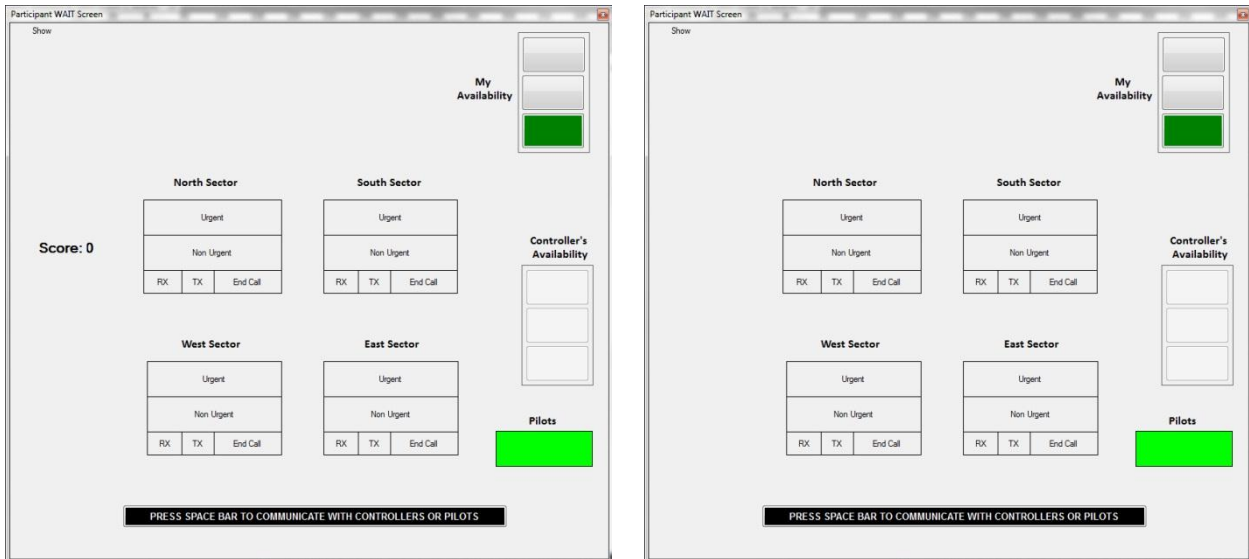
making other controllers aware of one's availability. Both interfaces also include the same urgency feature.

As shown in the left side of Figure 5.7, the Manual availability interface has an availability awareness feature in the form of levels positioned in the top-right corner of the screen. Participants can set their availability manually by pressing one of three buttons, Green, Yellow, or Red, to indicate whether they are available, possibly available, or not available, respectively. In addition, a performance score was added to the interface to help motivate participants in the evaluation experiment to actively use the availability tools. The score depends on the participants' availability selection: the most points a participant can have was achieved by selecting the green status, while the participant gets the least points by selecting the Red status. The score was a way to deter participants from setting-up their status as unavailable all the time, and to assess the usage of the developed feature in this interface variant.

The "Manual" display also provides on-demand information about the availability of other controllers. When the controller wishes to call another controller, they first select a communication channel button for the respective sector (e.g. West Sector). This action causes the availability level for that controller (e.g. West Controller) to be displayed on the right middle side of the display. The communication channel button for the sectors North, South, East, and West has two sub-divisions (urgent and non-urgent), which enables the controller to convey the urgency of the interruption. To make a call, participants click the sub-division that reflects their personal judgment of the urgency of the outgoing call. To proceed with the call, the controller presses the space bar which activates their microphone and enables them to make a voice transmission. The "Automated Availability" display has the same appearance as the "Manual Availability" as shown in the right side of Figure 5.7.



However, for this display the participant does not manually indicate their availability, but instead it is set automatically based on the number of aircraft controlled in the participant's sector (no score depends on this feature). There are no other differences between the functionality of the "Manual" and "Automated" versions of the WAIT tool.



**Figure 5.7: Manual (left) and automated (right) WAIT interfaces**

In all of the interfaces, participants respond to calls by pressing the spacebar, which opens the channel and highlights the transmission indicator "Tx" (in controller channels only) that indicates the call transmission. When participants receive calls, the "Rx" on the controller's channel button indicator becomes green to indicate the call receiving. If the participant is very busy and prefers to terminate the call with a controller, pressing the "End Call" button or calling another controller or pilot ends the call. Terminating the call with pilots is simply done by releasing the spacebar button.

## 5.2.2 Overview of the Experimental Environment

In order to evaluate the differences between the Control and each WAIT interface, the experiment put the participants in the place of air traffic controllers, and they are instructed to use the displays as explained earlier. An overview of the experiment setup is shown below in Figure 5.8. As depicted, the experiment is conducted in two physically separated rooms: the participant is in Room 1 and the experiment team is in Room 2.

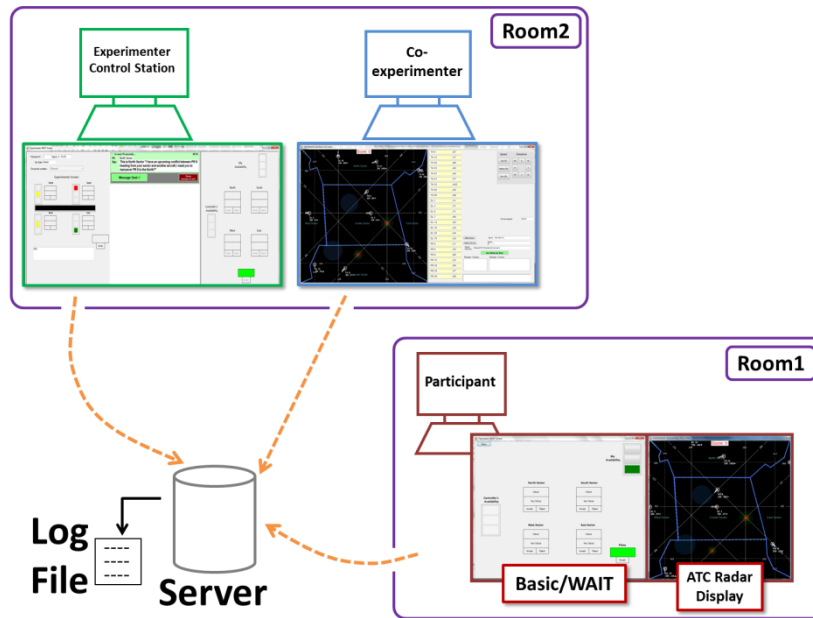


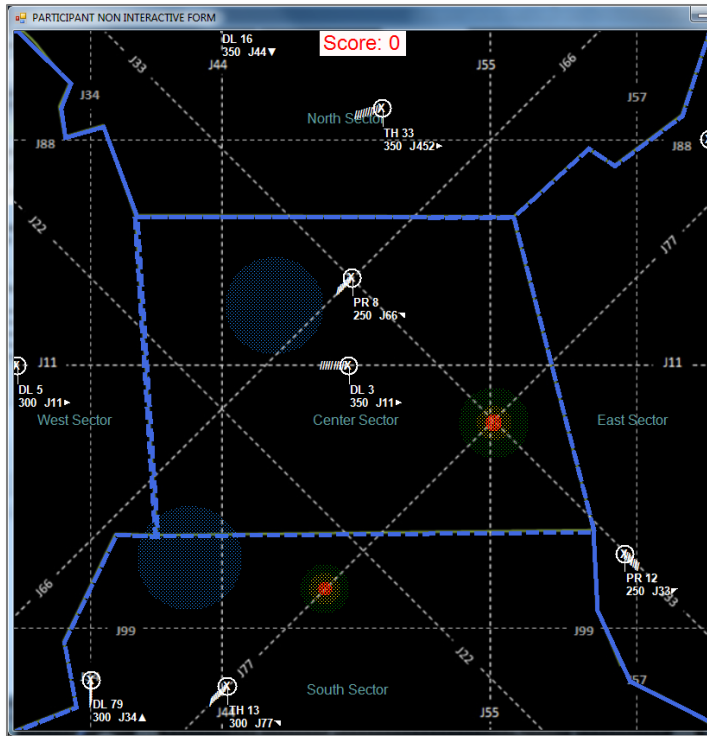
Figure 5.8: Experimental architecture

### 5.2.2.1 Participant Room Environment

In Room 1, the participant has a computer with two monitors. One monitor is dedicated to present training tutorial files (training design was discussed in the previous sub-section 5.1.5.2), and another ACER monitor (1920×1080 pixels) has the experimental screens including both a radar output from the ATC simulation and the Control/ WAIT interfaces. The left half of the second monitor shows the

Control/ WAIT interface (see Figure 5.6 and Figure 5.7). Participants communicate with any of the surrounding sectors on the map by mouse clicking a button on the WAIT screen. In addition to the mouse clicks, participants respond to the tasks using the keyboard spacebar key, headphones and an attached microphone. The spacebar key opens the channel to talk through the microphone.

The large black portion of the monitor is the radar output from an ATC simulation, presented in Figure 5.9. The ATC radar output is a non-interactive display that is positioned in the right half of the monitor. This display shows the aircraft movement within a geographical area, centered on the airspace being controlled “Center Sector,” but also including visibility into surrounding airspace that has other four sectors named North, South, East, and West for the ease of participants. Also included were eleven pre-defined routes for aircraft to move along named J11, J57, etc.



**Figure 5.9: Radar Screen**

As in Figure 5.10, each aircraft is attached to a data-tag that includes several pieces of important information. The first top-part of the data tag is an identifier for the aircraft consisting of an airline and a flight number. The left-bottom part of the data-tag is the aircraft's current speed in nautical miles per hour (knots) followed by a 2-digit path-line number that the aircraft should move along (origin and destination). Finally, it has a pointing arrow to show the destination direction of the aircraft. In Figure 5.10, the aircraft Porter 8 is currently going 250 knots and moving along line J66 to the northeast.



**Figure 5.10: Aircraft Data-tag**

All interactions and commands to change aircraft trajectories are given verbally through the Control/WAIT communications interfaces.

#### 5.2.2.2 Experiment-Team and Communication Environment

The experiment team (principle experimenter and co-experimenter) is located in Room 2, seated beside each other and able to share the view of each other's screens. Both members of the experiment team interact verbally with the participant through a communication system that has been built specifically for the experiment.

##### *Experiment team*

It was decided to run the experiment by a team and divide into two positions due to the complexity of the experimental tasks and roles. For instance, during the training sessions, two people were required to be present. While one person should accompany the participant in the small room to observe the participant's performance and provide help or clarification when needed, the other sits in the big room to run the training scenarios. Furthermore, the experiment includes some tasks that are very hard to handle at the same time by one person, such as talking to the participants as a pilot and making a call as a controller at the same time. Also, the different sources of information on the screens might shift the focus of the experimenter from responding to incoming requests or performing a required task.

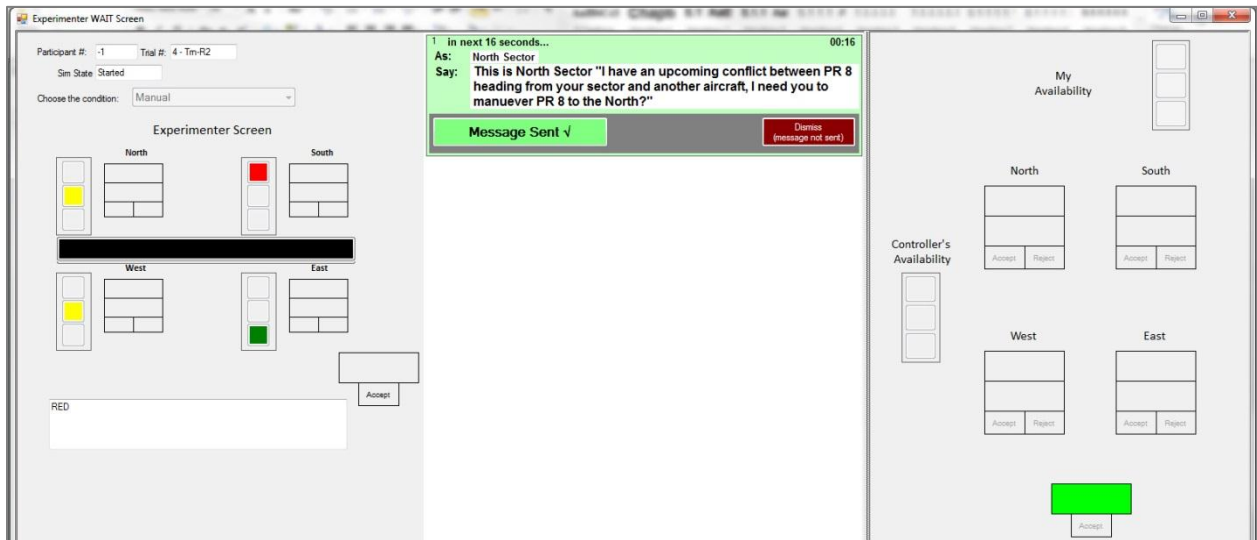
A significant concern was, for example, avoiding situations where an experimenter was busy responding to a previous request to change the heading of an aircraft to avoid a storm. During that time period, the experimenter may receive another call from the participant. This would require her to shift her gaze from the radar screen and look at the intended controller-receiver's availability status on the experimenter communication screen to decide the correct response based on the urgency of the call (see planned response system Table 5.5). At the same time, an interruption message appears on the experimenter screen asking to convey this message to the participant. Then in a few seconds, the participant calls the pilot, which requires the experimenter to shift her gaze back to the ATC radar screen and answer the call as the pilot. All these actions could happen in less than a minute.

The solution was to add another person to help make an efficient communication environment. Also, it was an attempt to emulate an aspect of the real environment communication by having different voices communicating with the participant. Additionally, if there were any errors that occurred during the experiment, having a partner would help to discover, remind, or correct the other person about these errors. This was proved during the experiment, not to mention the need for immediate assistance sometimes in making decisions to un-predictable situations. Another reason for having a team is to assist in the training sessions as mentioned earlier.

#### **PRINCIPLE EXPERIMENTER ROLE AND SCREEN SET-UP**

The principle experimenter has a communication interface that is divided into two parts; the left part is her view of the Control/WAIT screen (Figure 5.11 far left). Another part of the communication interface, Figure 5.11 (far right), clones the participant's Control/WAIT screen in order for the experiment team to observe the participant's performance from outside experimental room. In the center of Figure 5.11, an area is reserved for displaying messages that the principle experimenter used

to call the participant about in order to generate systematic and controlled interruptions. This emulated interruptions that would be caused by a surrounding controller needing information from the participant or having a question about how the air traffic situation would be controlled. More details on the interruption messages are presented in a following sub-section.



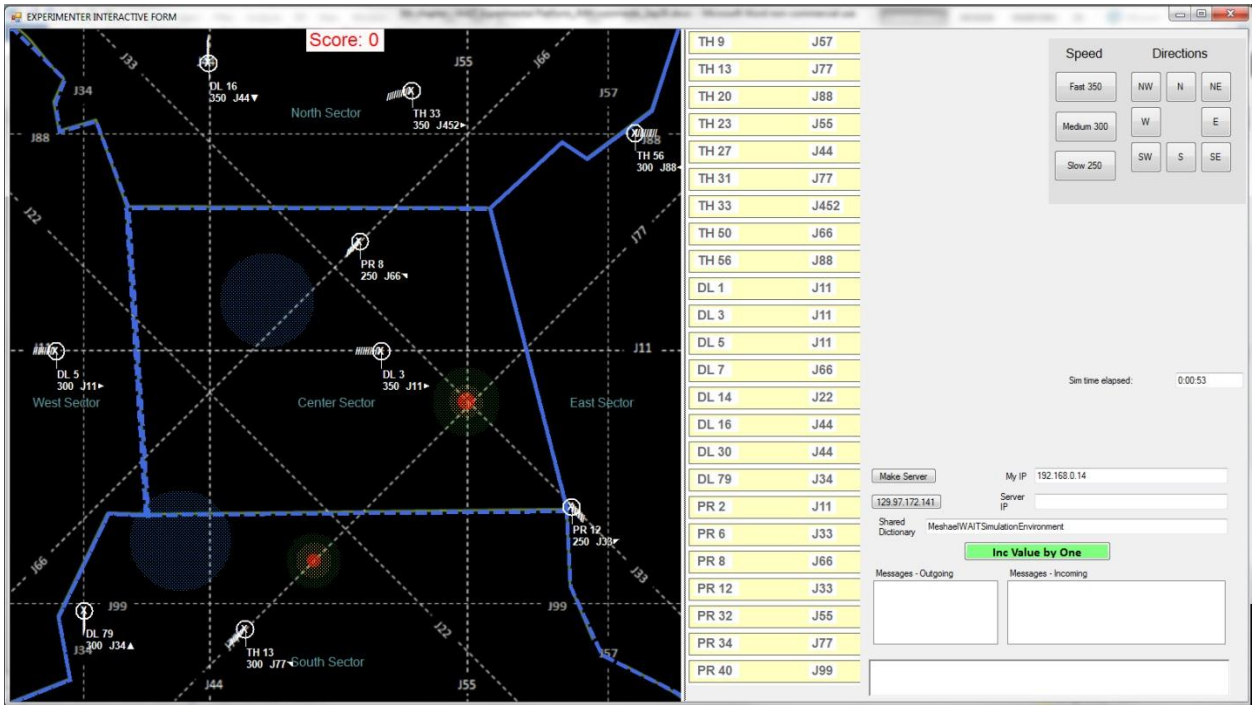
**Figure 5.11: Principle experimenter communication interface**

The principle experimenter is also responsible for representing the controllers of surrounding airspace and interacting verbally with the participant. In Manual and Automated conditions, each sector channel within server-side experimental communication screen is attached with an availability indicator. This availability is shown to participants when they call a particular sector and is pre-determined and varied over time. These values were stored as part of a scenario definition file and automatically used by the software as needed with no action required by the principle experimenter.

#### **CO-EXPERIMENTER ROLE AND SCREEN SET-UP**

The co-experimenter is responsible for representing the pilots in the airspace, and will respond to a participant's instructions directed to the aircraft pilots within the participant's sector, but will ignore instructions to pilots of aircraft that are not within the participant's sector. The co-experimenter is also responsible for implementing, through an interactive version of the ATC radar display, any modifications to aircraft trajectories that would result from instructions given by the participant to other controllers. To illustrate, as shown in Figure 5.12, the co-experimenter's control panel (positioned in the far right corner) in the interactive radar screen has three levels of "Speed" on buttons (fast, medium, and slow). The speed levels are provided for the participant to request help in controlling aircraft in their sector. Similarly, the co-experimenter responds to heading changes requests by pressing any of the "Directions" buttons (north, northeast, east, southeast, etc.) for the selected aircraft. There are no altitude controls, as all aircraft are set to be flying at constant altitude to minimize traffic complexity.





**Figure 5.12: The co-experimenter's integrative version of ATC radar display**

When a participant wants to change the direction or speed of any aircraft moving in the radar display, they communicate this to the responsible controller or pilot. The experiment team then applies the changes. This setup was designed to eliminate the need for participants to learn an interface with the computer system, with the goal of minimizing the necessary training time during the experiment. This setup also emulated closely the verbal nature of current air traffic control operations and the need to manage verbal, communication channel driven interruptions.

### *Connection and communication*

### **INTERRUPTIONS**

To find the difference between the Control interface condition and the WAIT Manual and Automated interface conditions on participants' performance with interruptions from the experimenters,

systematic interruption messages were created. In the Control condition, all messages were always communicated to the participant because there is no way for the participant to indicate an availability status. In contrast, interrupting the participants with messages in the Manual and Automated conditions was affected by the set status of the participant’s availability.

There were nine messages categorized in three main categories. Three of these messages related to high critical issues such as aircraft conflict or aircraft entering a storm area, while another three were related to less critical issues such as an aircraft entering into a weather turbulence area. The last three messages were about non-critical, but task relevant issues, such as requesting information about an aircraft speed or heading.

A response system to show or hide messages based on the participant’s availability was created for the experimenter to be consistent among each study’s three trials specifically and among the entire participants in general (Table 5.5).

**Table 5.5: Interruption messages response system**

(Check mark indicates message would be shown to the experimenter)

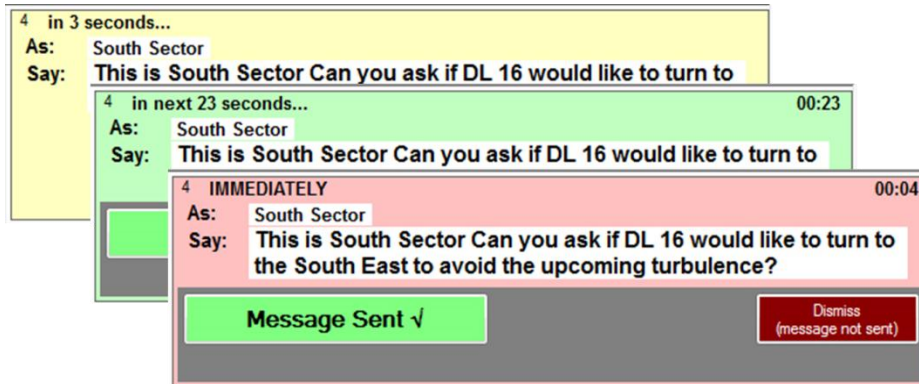
<b>Participant Status</b>	<b>Message Content</b>		
	<i>Conflict or Storms</i>	<i>Turbulence</i>	<i>Other matters</i>
<i>Red</i>	✓	×	×
<i>Yellow</i>	✓	✓	×
<i>Green</i>	✓	✓	✓

The message categories were created based on the causes of the score deduction on the participant’s radar screen. For instance, the two highest score deductions are caused when an aircraft collides with

another aircraft, or when an aircraft enters a storm. Therefore, the most critical category regards these two situations.

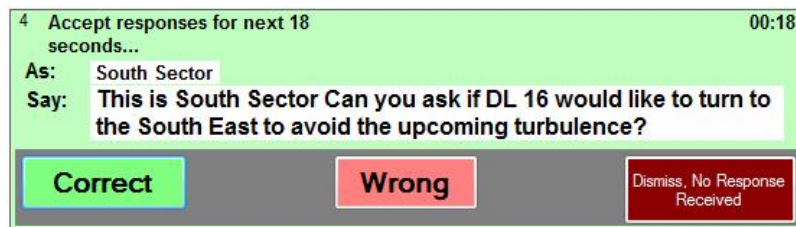
To illustrate how this was implemented in practice, once a message appears for the experimenter on her communication screen, the availability status that the participant was currently showing was checked once against the required availability for the message to be sent. For example, if the interruption message was about informing the participant about a potential turbulence along the line of an aircraft he/she is controlling, and the participant's availability was set to Yellow, meaning that the participant is possibly available, the software tests what category the message belongs to and then keeps the message present on the experimenter's display.

During the 10 minute trials, the designed interruption messages were distributed at approximately one minute intervals. The timing of the messages was pre-determined and also stored in the software. Each message was presented to the experimenter for 30 seconds in total. During the first four seconds, the message appears in a yellow box to warn the experimenter about the incoming message. At that time, the required availability of the message is tested against the participant's current availability, as described in the previous paragraph. If the message should be passed to the participant, it will remain in a green box for 20 seconds with a timer positioned on the top right side of the box (Figure 5.13) to make the experimenter aware of the ending time. In the last remaining 5 seconds, the message becomes surrounded by a pink box to motivate the experimenter to finish conveying the message immediately before it is gone. The message also shows which sector-controller the experimenter should play the role of in the second line of the message box. In this way, the experimenter spends less mental workload because many steps have been automated, and the required information is provided clearly within the message.



**Figure 5.13: An example of an interruption message’s three stages when appeared**

Moreover, different buttons were shown in the message box to help automate logging of the data relevant to each message. These buttons were used to determine if/when the message was sent (“Message Sent”) or dismissed (“Dismiss”). If sent, whether it was correct/positive (“Correct”), or if a wrong/negative (“Wrong”) answer was given by the participant (Figure 5.14).



**Figure 5.14: Logging interruption messages data using the option buttons**

#### CONTROLLING THE RESPONSE TO PARTICIPANTS’ CALLS

In Control condition, the experimenter answers all incoming calls from participants as possible. However, in Manual and Automated conditions, the response to the calls is different. The experimenter takes into consideration both the urgency level of the incoming call from participants and the controller’s interruptee availability status. To measure the effect of providing participants

with the availability status of the controller receiver and the urgency level of outgoing calls, a response table containing systematic responses was created based on the availability of the controller receiver ( Table 5.6). For example, if the participant’s call was non-urgent to the North sector controller, the experimenter looks at the North controller’s availability status (e.g. Red), and the response of the controller should be to ignore the call.

**Table 5.6: Response system to calls from participants**

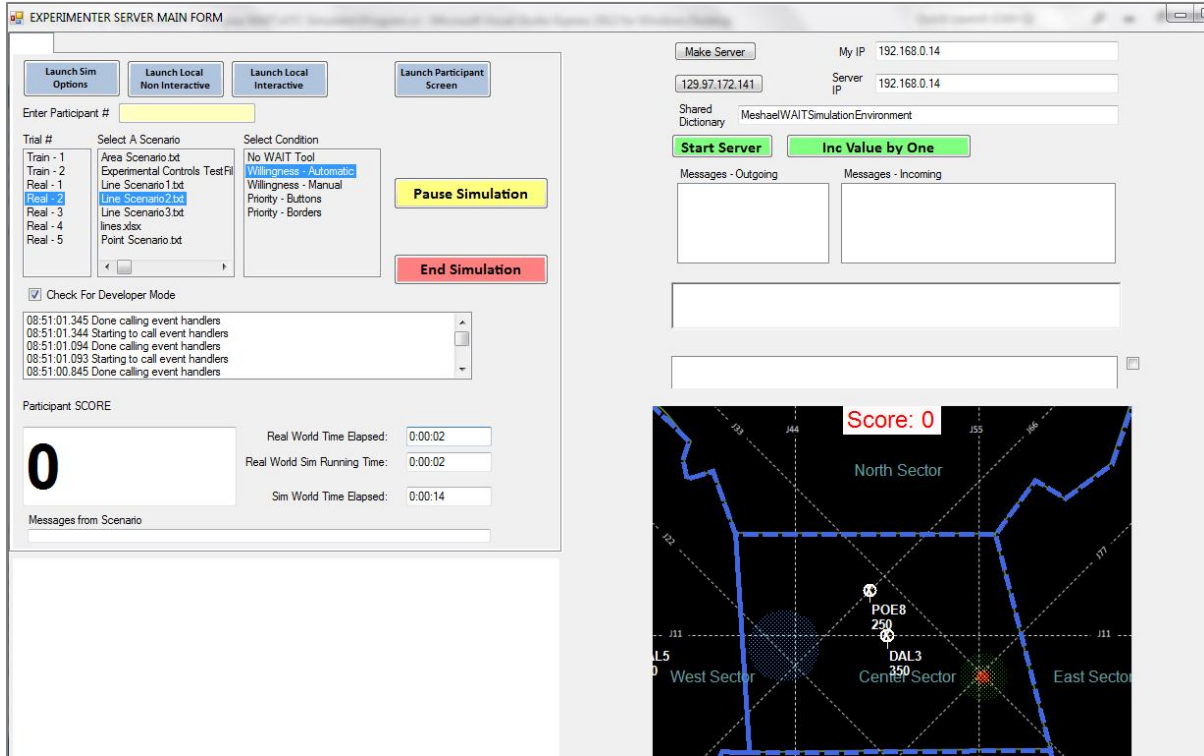
(Check mark indicates participant’s call would be answered)

<b>Controller Status</b>	<b>Call Urgency Level</b>	
	<i>Non-urgent</i>	<i>Urgent</i>
<i>Red</i>	×	✓
<i>Yellow</i>	Experimenter’s momentary decision	✓
<i>Green</i>	✓	✓

#### EXPERIMENT SIMULATION CONTROL STATION

The ATC Simulation server controls all programs and networking connection; it is also used for generating each participant’s different training and data collection sessions (Figure 5.15 left). The Simulation server interface provides the ability to log the information of each participant, such as the participant ID, the interface condition, and the scenario number at the outset of each study trial. The interface also provides some options like the timing of the aircraft movement and experimental events. The simulation to real time ratio that was used when conducting the experiment was 1:5, but it was editable if needed for testing purposes. The dimensions of the viewable area of the radar screen were fixed at 200 nm by 200 nm. The screen was stretchable based on experimenter team needs.

However, the participant view of the radar screen has a fixed size which was maximized to the monitor's height and occupied half of the monitor's width, as mentioned earlier.



**Figure 5.15: Simulation server interface**

All the interfaces in this platform are synchronized through the simulation software located on the server in Room 2. Moreover, the experiment team has the same view of the participant's radar screen to allow for observing the participant's performance synchronously.

#### **VOICE COMMUNICATION THROUGH SKYPE**

Voice communication was established through the Skype application running in the background of the participant's and experiment team's computers. Special code was added to the spacebar key press

and release events in order to mute/unmute the sound system when calls occur. This creates a semi-realistic voice transmission between the experiment team and the participant.

### **5.2.3 Modifications and Simplifications Made to the Experiment Platform Identified During the Development of the Study**

The lack of expert participant affected the interfaces, tasks, and communications used in the experiment. Creating an appropriate experimental environment that emulates the complexity of the ATC environment, yet is able to be dealt with by non-expert participants, was challenging. To address the limitations that were identified during the tool development and which emerged during the multiple pilot tests, modifications were made to some aspects of the experiment plan and software. The following paragraphs discuss some of the key challenges encountered, lessons learned about the software, and the experimental environment and tasks.

#### **5.2.3.1 Communication with Experimental Team**

A key design consideration was how realistic to make the communication protocols between participants and the experimental team. There is a trade-off between realism and the training needed to have participants function effectively with the communication protocol. While there is a desire to be consistent with the actual communication procedure that occurs between controllers and pilots in the real world, the participants and experimental team lacked ATC and piloting experience meaning there would be a need for significant training time.

Several changes were made to make the interfaces and protocols more accessible to those with little to no real-world aviation experience. A button was added to the participants' Control/WAIT interface to show them when they are connected to pilots. In real-world ATC, an air traffic controller by default

is connected to the controller-pilot radio frequency with no specific button on their communication screen needed to connect them to pilots. Additionally, a communication protocol was created to assure that the time spent in communicating control information is equivalent among all participants, and to make it easier for the experiment team to understand what participants say even if their speech was not very clear. Establishing this communication phraseology to be used by the participants helps in creating a speech mental model for both sides of the communication.

#### 5.2.3.2 Information about the Moving Aircraft

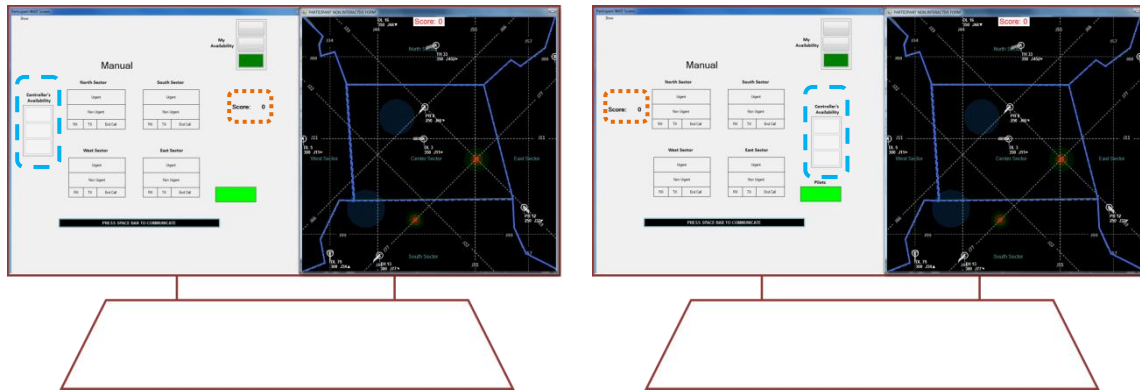
Air traffic controllers in real ATC environment receive a flight plan for aircraft in their sectors. During the preliminary pilot tests, it was difficult for the experimenters and for the participants to keep track of the aircraft movements along the path-lines without such a flight plan. Therefore, information was added into the data tag attached to each aircraft moving on the radar screen to represent the origination and destination of the aircraft. This would help the participant to know where the aircraft is supposed to head to. Later on, a list that resembles part of the flight plan was added to the co-experimenter's interactive screen to help reduce the time spent searching for aircraft on the map. During the pilot tests, it was clear that time spent searching was a reason for missing many events and resulted in low quality communication. The center area of the screen in Figure 5.12 that has a yellow background shows the flight list that was added to adapt the simulation platform, and subsequently improved handling the communication tasks for the experiment team.

#### 5.2.3.3 Software Interface

Pilot testing showed that the initial placement of the indicator that shows controller's availability in the participant Control/WAIT interface was in a poor location. It was moved from the far left side to the right side of the screen to ease the eye shifting between the different areas of the screen. Since the



Control/WAIT interface is positioned on the left side of the monitor, and the radar is positioned on the right side of the monitor, and that the focus of the eye is usually in the center, moving the availability panel to the right side of the interface was useful as depicted below in Figure 5.16.



**Figure 5.16: Participant screen’s controller availability panel was moved from the left side of the WAIT panel to the right side (Left: Before modification, Right: After modification)**

#### 5.2.3.4 Participant Tasks

During the preliminary pilot tests, participants were responsible for handling aircraft “handoffs” as aircraft entered or exited the sector. It was observed that this added to only some participants workload because others were either not concerned about it (since it does not affect their score), or they tended to forget to perform it as the time passes, which created differences between participants performance that cannot be measured. Therefore, the decision was made to eliminate the “handoffs” from participants’ tasks.

### 5.3 Summary

This chapter outlines how the thesis third objective presented in Chapter 1 is addressed using a human-in-the-loop experimental platform. Developing experimental protocols to test complex

phenomenon like interruptions is very challenging. The chapter has described how these challenges required the development of specific communication protocols for participants and the experiment team. In addition, rotation techniques were presented to help develop equivalent, but novel air traffic scenarios to each participant to ensure that observed differences were not a result of scenario differences. The experimental room set-up, the communication and networking system, and the experimental team and participant placement were described in this chapter in detail.

The resulting experimental platform emulates the complexity and collaborative nature of the ATC environment. It has been used to evaluate more closely the effects of the two main aspects of the developed WAIT tool (availability feature and call urgency levels feature). Limited participant time resources meant that only a sub sampling of the three availability conditions (control, manual, and automated) and two urgency level conditions (appeared and hidden) could be evaluated.

The final Control/WAIT screens that were tested were also presented. The chapter ended with the modifications that were made to simplify the real air traffic control screens to be consistent with the participants lacking ATC experience.

The next chapter will discuss in detail the analysis and the results of the study. It identifies a number of important design lessons, relevant for other researchers interested in testing complex phenomenon like interruptions in controlled but realistic environments.

## Chapter 6

### User-study Analysis, Results, and Discussion

*“Given the complexities of human-human communication and group working, it is hardly surprising that experimental studies of groups and of groupware are more difficult than the corresponding single-user experiments.” (Dix et al., 1998, p.540)*

This chapter describes the data collection techniques, evaluation methodology used and results of the WAIT evaluation user study described in Chapter 5. Lessons learned and recommendations for other researchers studying interruption behavior and tools are presented.

#### 6.1 Data Collection

In order to assess differences between the WAIT implementations, several forms of data were collected:

***Audio and Video Recordings.*** In order to capture the verbal and physical behavior of the participants, audio and video recordings were collected. Video analysis provides insight into reasons why features are or are not effective. For example, the use of both the mouse when clicking on certain buttons and the touch screen when pressing other screen buttons can have different implications.

***Questionnaire and Interview Responses.*** During the study, questionnaires were administered after each data collection session, as well as a final overall post-test questionnaire that include questions asked participants to self-rank their performance. Participants also participated in a post-experiment

interview about their experiences with the tool. Both questionnaires and interviews provided rich information which helps to fill the gaps from the other data sources.

***Performance Measurements.*** Scores on the WAIT task and ATC separation task were recorded and used to assess performance differences between the experimental conditions.

***Log Files.*** Both the ATC radar and WAIT interfaces provide extensive data-logging capabilities; this allows for detailed examination of participant performance in the different experimental conditions. For example, data on the time taken to respond to incoming calls was collected for further analysis. In addition, for outgoing calls made by a participant, the availability level of the controller being called is logged. This provided insight into how much of an effect the availability awareness features are having on participant behaviors. For example, participants may start a call to a controller who has a “Red” availability level and subsequently terminate the call before beginning to talk. Comparing how frequently this occurs in the different conditions, and whether such behavior is present at all in the baseline sessions, provided insight into the effectiveness of the interruption tools provided by the WAIT interface.

## **6.2 Analysis**

As a subset from the methods used for data collection, only questionnaire, interview, and some performance measurements analysis were used to present the results in the thesis. The analysis was performed to evaluate the effectiveness of the WAIT tool on interruption management. The following sections present the results of the analysis.

Note that some of the graphs were prepared using the “R” statistical plotting software as a way to present the data more clearly. The commands used are reported in Appendix K.

### 6.2.1 Objective Scores

In each trial, a radar screen score was collected for each participant; this score reflected their performance on the underlying ATC task. Points were deducted for errors including aircraft-aircraft collisions, aircraft-weather encounters, and aircraft-turbulence encounters. Scores were calculated as deductions for each type of error made (see Section 5.2.2.2) and are presented in Figure 6.1. In the figure, the scores are presented as the total deduction (more negative means a worse performance). Figure 6.1 shows that the average performance was best in the Automated interface condition (least negative score), followed by the Manual interface condition and the Control interface condition. This is indicative of the interruption management tool having a substantive effect on overall participant performance.

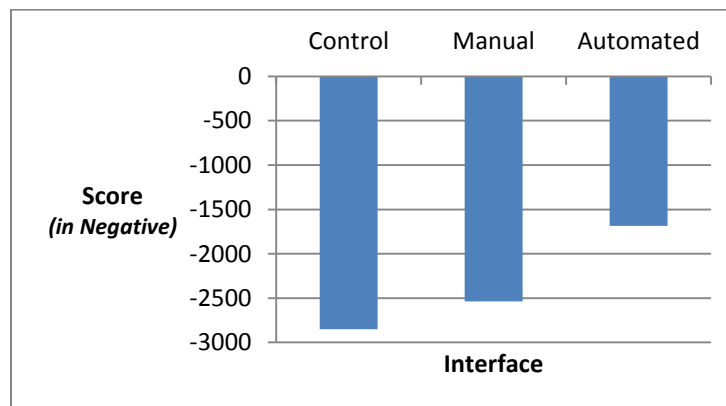


Figure 6.1: Average of participants' radar screen score as a function of interface condition

### 6.2.2 Questionnaires

The questionnaire data responses were collected through the tool (surveymonkey.com); outputs were then processed and analyzed using Microsoft Excel to find statistical findings. Two types of questionnaires were collected: post-trial questionnaires that the participants filled out after each

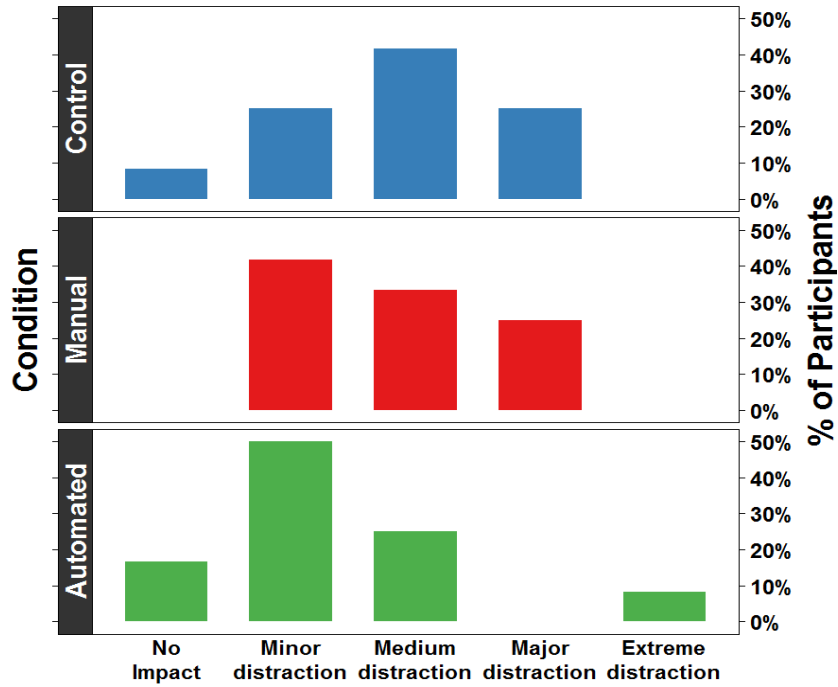
experimental trial, and the overall questionnaire that they filled out after the completion of the three trials and before the interview session.

#### 6.2.2.1 Post-Trial Questionnaires

##### *Distraction effects of interruptions*

First, participants were asked to rate the distraction effect caused by the interruptions from other controllers. Figure 6.2 and Table 6.1 below compare participant responses to the levels of distraction in the three interfaces (Control, Manual, and Automated interface).

The figure shows that there is some evidence of a shift towards lower distraction for the Automated and Manual conditions. The mode of both the Automated and Manual conditions is “minor distraction” while the mode for the Control condition is “medium distraction.” In the Automated interface condition (green), more than half of the participants reported “no” or “minor distraction” from interruptions from other controllers. In contrast, the Control condition (blue) had two thirds of the participants reporting “medium” or “major distraction” from interruptions from other controllers. The Manual condition (red) falls in-between with over half but less than two thirds of the participants “medium” or “major distraction” from interruptions from other controllers. Finally, the median rating for Automated condition was also “minor distraction” while the median rating for the Control and Manual conditions was “medium distraction.” This suggests participants were finding reduced effects of distraction in the Automated condition, and to a lesser extent the Manual condition, as compared to the Control condition.



**Figure 6.2: Distraction effect of interruptions from other controllers (in percentage)**

**Table 6.1: Distraction effect of interruptions from other controllers (# of participants)**

	No Impact	Minor distraction	Medium distraction	Major distraction	Extreme distraction
● Control	1	3	5*	3	0
● Manual	0	5*	4	3	0
● Automated	2	6*	3	0	1

\* indicates the mode for each condition

The following question examined the distraction effect created by interrupting other controllers. For all conditions, most of the participants gave distraction ratings in the no-impact/minor/medium distraction categories with relatively little difference in the overall distribution of ratings between conditions (see Figure 6.3 and Table 6.2). There is some indication that the Manual interface condition was perceived as having less distraction associated with interrupting other controllers with

twice as many participants (33.3% vs 16.7%) reporting there being no impact. The ratings of the Automated and Control interfaces showed similar distributions.

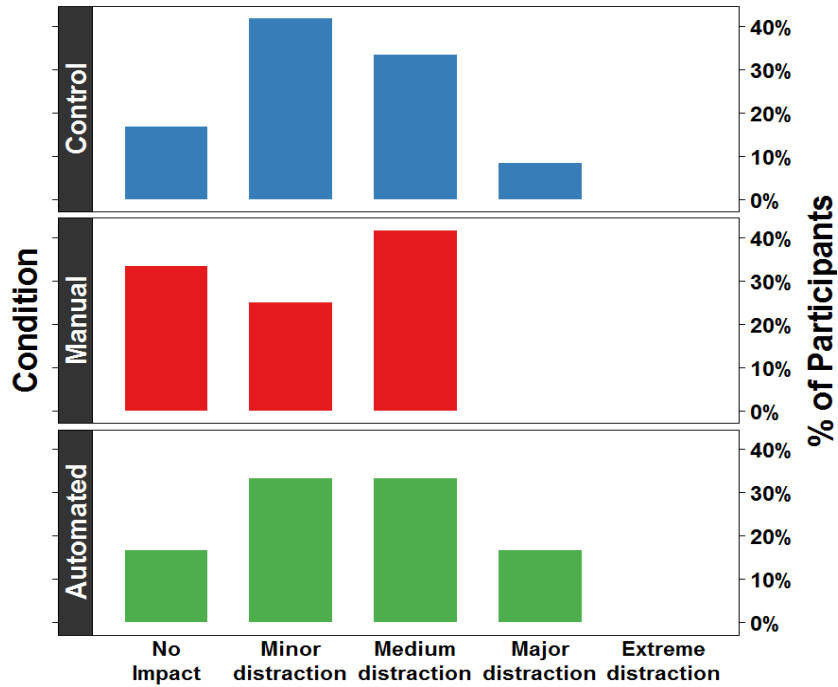


Figure 6.3: Level of distraction of interruptions to other controllers (in percentage)

Table 6.2: Level of distraction of interruptions to other controllers (# of participants)

	No Impact	Minor distraction	Medium distraction	Major distraction	Extreme distraction
● Control	2	5*	4	1	0
● Manual	4	3	5*	0	0
● Automated	2	4*	4*	2	0

\* indicates the mode for each condition

### *Self-reported level of effective communication and overall performance*

Participants were asked to rate their ability to communicate effectively. Figure 6.4 and Table 6.3



show that most of the participants felt they were able to communicate effectively at least some of the time, and no participant reported feeling unable to communicate at any time. There do not appear to be any substantive differences in how the interface conditions affected participant perceptions of their ability to communicate effectively.

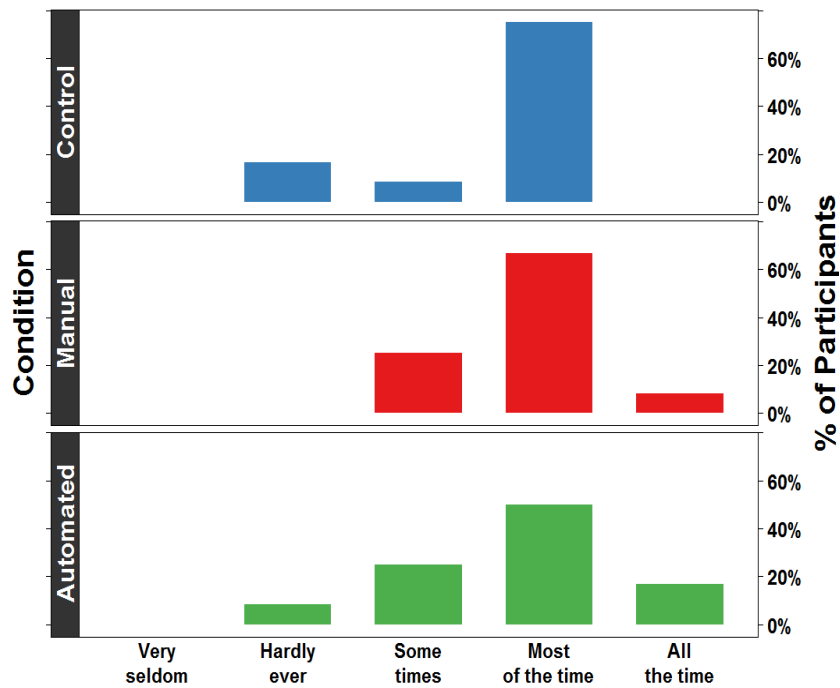


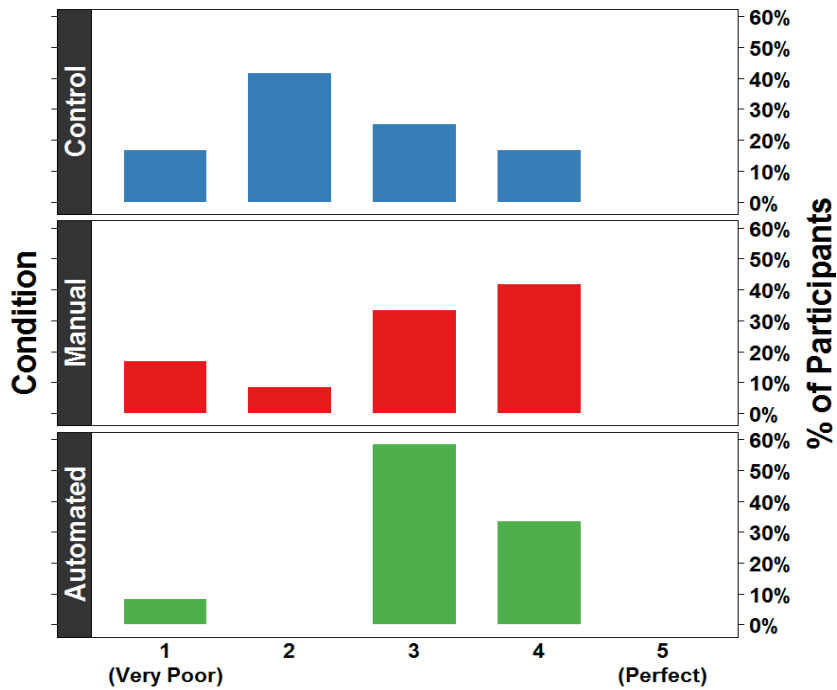
Figure 6.4: Ability to have effective communication (in percentage)

Table 6.3: Ability to have effective communication (# of participants)

	Very seldom	Hardly ever	Some times	Most of the time	All the time
● Control	0	2	1	9*	0
● Manual	0	0	3	8*	1
● Automated	0	1	3	6*	2

\* indicates the mode for each condition

The next question asked participants to self-rate their overall performance. Figure 6.5 and Table 6.4 show the distribution and the number of participants, respectively, of ratings for each interface condition. Figure 6.5 shows that the Automated interface and Manual interface conditions both had higher self-ratings of performance than that of the Control interface condition. As seen in Figure 6.5, over 90% of the participant ratings in the Automated interface condition were “3” or above, 75% of the participant ratings in the Manual interface condition were “3” or above, while over half of the participant ratings in the Control interface condition were “2” or below. These results also suggest a slightly better self-perception of performance in the Automated interface condition as compared to the Manual interface condition.



**Figure 6.5: Overall performance (in percentage)**

**Table 6.4: Overall performance (# of participants)**

	1 (Very Poor)	2	3	4	5 (Perfect)
● Control	2	5*	3	2	0
● Manual	2	1	4	5*	0
● Automated	1	0	7*	4	0

\* indicates the mode for each condition

As part of the question of overall performance, participants were asked to comment on the rating they provided. The comments were reviewed for common factors participants cited as affecting their performance negatively. Table 6.5 shows the common factors identified for each interface. It is clear that participant comments on the various interfaces did not include any negative factors about the tool itself in the Automated interface, as compared to the factors of Manual interface (Table 6.5). Factors

associated with the task (re-routing aircraft, misjudging speed) and radar display (locating targets, monitoring out-of-sector aircraft) were common to all or multiple interface conditions. Of note are comments suggesting that participants found the Manual condition, where they had the additional task of setting their own availability, overwhelming. There are also indications that participants recognized they could have reduced the number of calls but did not take advantage of the availability feature.

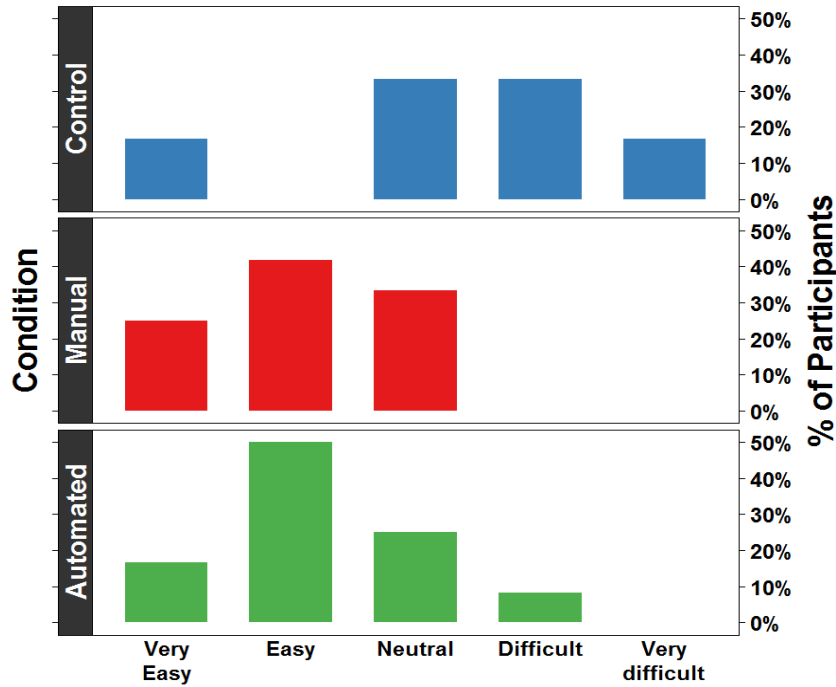
**Table 6.5: Factors affecting the performance negatively in the different interfaces**

Conditions:	Factors	Control	Manual	Automated
All	Locating targets	✓	✓	✓
	Re-routing aircraft back to its original pre-set path lines	✓	✓	✓
Control and Manual	Inefficient monitoring out-of-sector aircraft to avoid collisions	✓	✓	
	Misjudging speed of the aircraft	✓	✓	
Control Only	Making wrong calls	✓		
	Remembering the communication protocol	✓		
Manual Only	Feeling overwhelmed		✓	
	The lack of using the availability feature to lessen the received calls		✓	
Automated Only	Too much interruptions from others accompanied with ineffective response from the participants			✓

***Wait features: Urgency level and availability***

The next question asked participants to rate the difficulty level of communicating the urgency of outgoing calls. Figure 6.6 and Table 6.6 show, unsurprisingly, that the Automated interface and Manual interface conditions both had higher self-ratings of easiness compared to that of the Control interface condition. This is because the Control interface lacked this feature. As seen in the graphs,

most of the participant ratings in the Automated interface and Manual interface conditions were shifted to the right (Neutral, Easy, and Very Easy).



**Figure 6.6: Difficulty of communicating the urgency of outgoing calls (in percentage)**

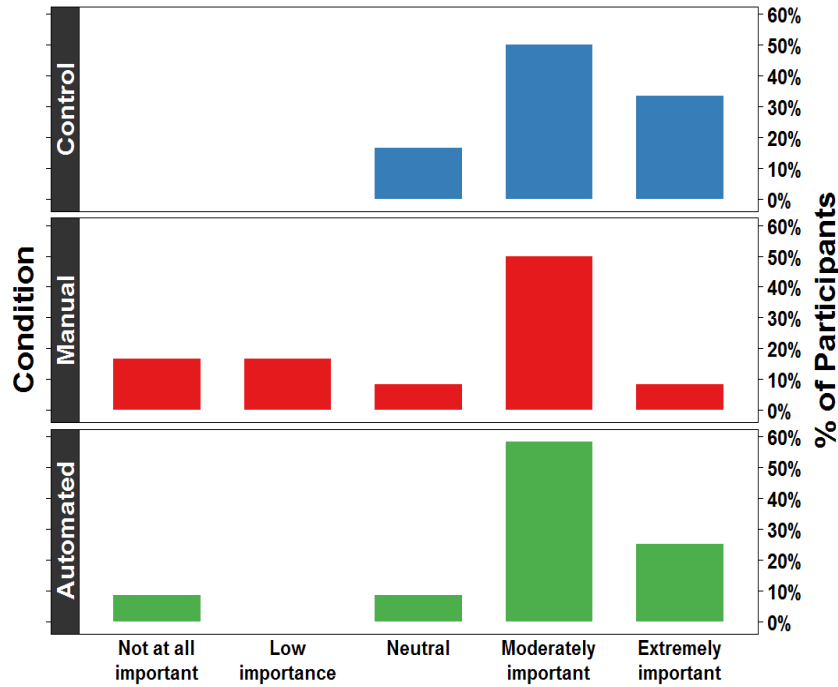
**Table 6.6: Difficulty of communicating the urgency of outgoing calls (# of participants)**

	Very Easy	Easy	Neutral	Difficult	Very difficult
● Control	2	0	4*	4*	2
● Manual	3	5*	4	0	0
● Automated	2	6*	3	1	0

\* indicates the mode for each condition

Figure 6.7 and Table 6.7 below show that the participants felt it was important to convey their availability to the other controllers in all interfaces. Interestingly, the one condition where participants were required to actively take steps to convey their availability (the Manual interface condition)

showed a lower proportion of participants rating it as “extremely important,” and a higher proportion of participants reported it as being of “low importance” or “not at all important”.



**Figure 6.7: Importance of conveying level of availability to other controller (in percentage)**

**Table 6.7: Importance of conveying level of availability to other controller (# of participants)**

	Not at all important	Low importance	Neutral	Moderately important	Extremely important
● Control	0	0	2	6*	4
● Manual	2	2	1	6*	1
● Automated	1	0	1	7*	3

\* indicates the mode for each condition

Next, the participants were asked about how difficult it was to convey the level of availability to other controllers. Obviously, the easiest interface to handle this issue was the Automated interface. It is not surprising that the Automated and Manual interfaces were not difficult/very difficult to convey the

level of availability since an availability feature is provided in these interfaces but not in the Control interface (see Figure 6.8 and Table 6.8).

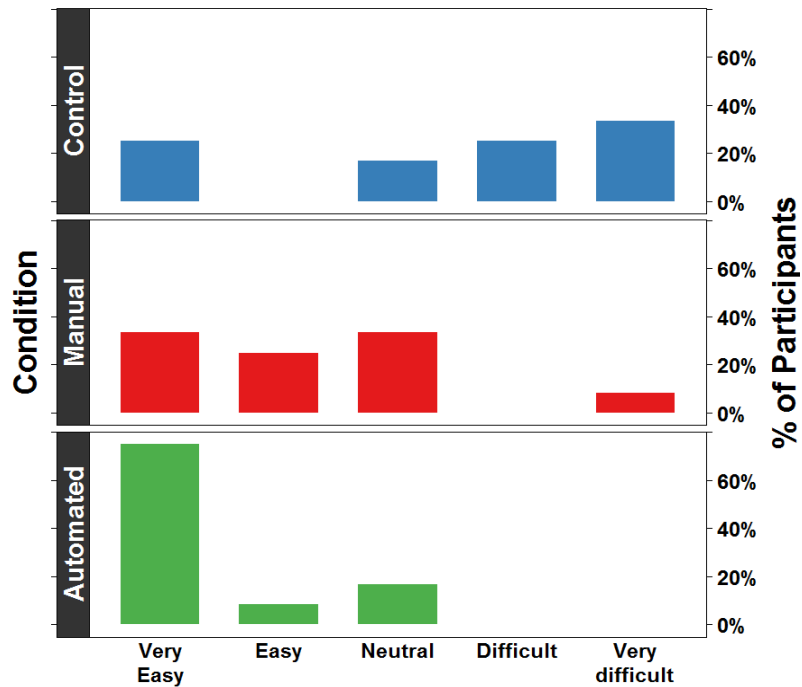


Figure 6.8: Difficulty of conveying level of availability to other controllers (in percentage)

Table 6.8: Difficulty of conveying level of availability to other controllers (# of participants)

	Very Easy	Easy	Neutral	Difficult	Very difficult
● Control	3	0	2	3	4*
● Manual	4	3	4*	0	1
● Automated	9*	1	2	0	0

\* indicates the mode for each condition

After that, participants were asked to provide examples of the techniques that they used other than the provided features to convey their level of availability. In the Control interface, the examples collected were “By ignore giving answers to unimportant questions” or by “Conveying the availability verbally.” In Manual, participants mentioned they conveyed it through the tone of the voice or by

delaying responding to incoming calls. Finally, in Automated interface, they were able to convey availability by continuing speaking in the active call if another call was ringing at the same time, thereby ignoring the incoming call.

Similarly, participants were asked to describe the techniques they used to convey the urgency level to other controllers in the Control interface. Examples of the techniques received are tone of voice, verbal indication, and/or conveying the reason of urgency (e.g. "crash").

#### 6.2.2.2 Overall Questionnaire

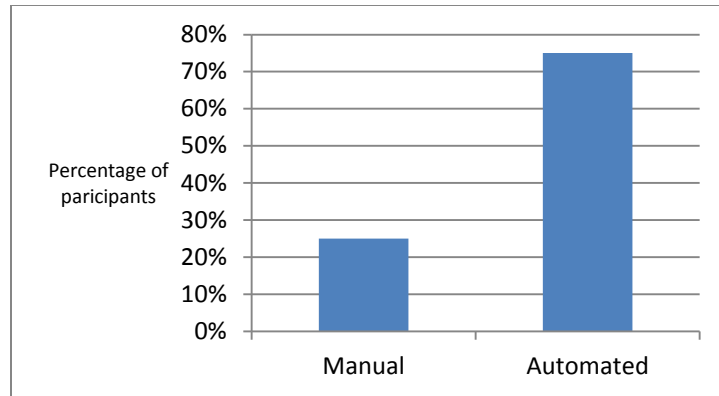
In addition to the post-trial questionnaires, a final overall questionnaire was administered at the conclusion of each participant experimental session (see Section 5.1.5). This provided opportunities to compare perceptions of the Manual and Automated interfaces directly for both the availability and urgency features. Some questions also asked participants to add comments or reasons explaining their answers; in the results presented below, these comments were analyzed and categorized into common themes and the frequency of those themes are presented.

##### *Availability features and managing interruptions.*

The second objective of the experiment was to determine, assuming an interruption availability tool is present, which version (Manual or Automated) was preferred by participants. This was examined through three questions, the results of which are presented below.

First, participants were asked to select the availability feature representation (Manual or Automated feature) they found most helpful for managing interruptions from other controllers. 75% of the participant preferred the Automated availability feature while 25% preferred the Manual feature representation (see Figure 6.9).





**Figure 6.9: Which representation of the Availability feature did you find most helpful for managing interruptions?**

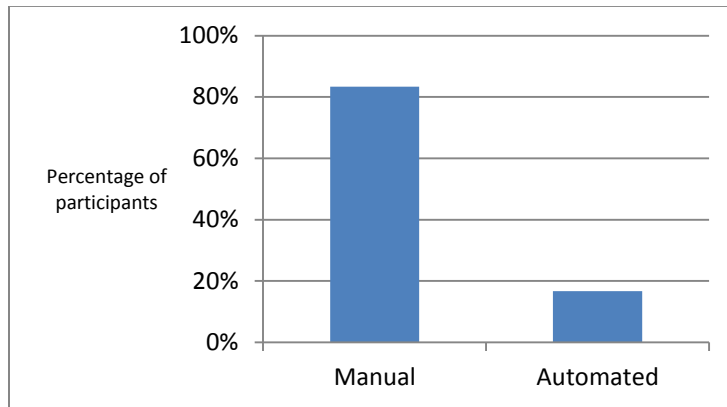
After that, participants were asked to explain the reason for their answer. For those who preferred the Manual interface representation, only one participant made a comment, stating “The controller best determines his availability. There might be a large number of aircraft but they are not posing any difficult situation.” The explanations made by those who preferred the Automated interface representation are summarized and listed below in Table 6.9.

**Table 6.9: Reasons for preferring the Automated interface availability feature in managing interruptions**

Reasons	Percentage of comments
Saves the time spent in cognitive work	45%
Requires less workload	27%
Provides the ability to focus on control task	18%
Number of aircraft is a good indicator of busyness	9%

Next, participants were asked to select the availability feature that was the hardest for managing interruptions. Participant responses are illustrated below in Figure 6.10. As seen, most of the

participants (83%) agreed that the Manual availability interface was the hardest in managing interruptions, while only 17% found the Automated availability interface the hardest.



**Figure 6.10: Which representation of the Availability feature did you find hardest for managing interruption?**

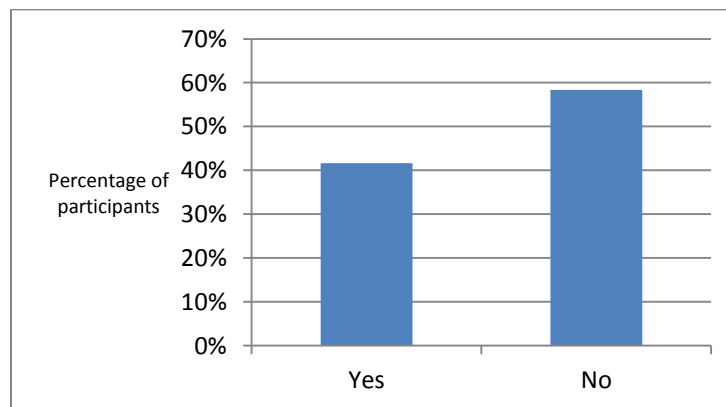
The reasons for finding Manual representation the hardest are summarized and listed below in Table 6.10. Interestingly, two participants who reported that the Manual availability representation is the hardest for managing interruptions also reported that the Manual availability is the most helpful representation at the same time. One of them commented on that by saying “Manual interface is hard as compared to Automated interface, but I think Manual interface is more effective”.

**Table 6.10: Reasons for finding the Manual availability representation the hardest**

Reasons	Percentage of comments
Requires extra time and/or cognitive power to manage it	42%
It is hard	25%
Causes distraction	8%
Creates additional task	8%
Does not help in properly prioritizing the air traffic controller's actions	8%
Things are always out of expectation.	8%

***Availability feature***

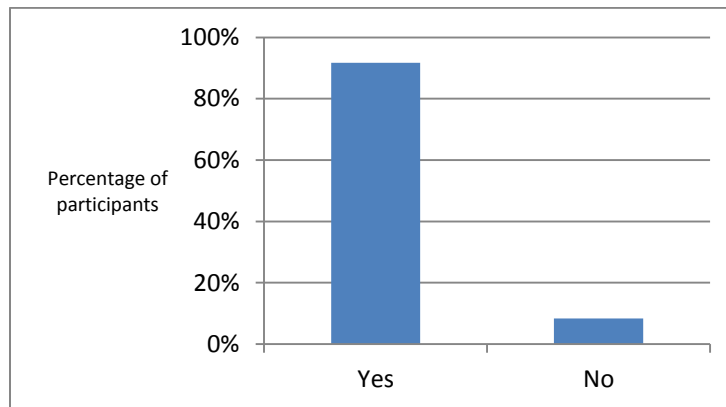
Participants were also asked if they ever intentionally set their availability in the Manual interface condition to control the types of interruptions they would receive from other controllers. 42% answered with “Yes” while 58% answered with “No” as seen below in Figure 6.11.



**Figure 6.11: “Did you ever intentionally use your level of availability feature to let other controllers know the status of your availability?”**

### *Urgency feature*

Participants were asked if they ever intentionally used the urgency level feature when calling other controllers. Most of the participants (92%) reported that they used it intentionally while only 8% answered with “No” (Figure 6.12).



**Figure 6.12: “Did you ever intentionally use the urgency level feature when calling another controller?”**

Participants were also asked to give examples of techniques they used to predict the urgency of incoming calls other than the features provided directly in the interface. As an answer to this question, one participant said, “If my availability is set to high, I'd assume that the incoming calls are urgent”. Another participant reported that it depends on the traffic density of the sector that the call comes from. Additionally, a participant stated that the speed of aircraft conveys how urgent the incoming requests would be.

### **6.2.3 Interviews**

As mentioned in chapter 5, each participant was also involved in a 10-15 minute interview session (see Appendix H for the interview questions). An audio analysis was performed on these interviews.

The analysis revealed more information about the utility of WAIT and the participants' behavior towards the interfaces provided.

When participants were asked to add comments or to give the reasoning behind their answers, these comments were analyzed and categorized into common themes; the frequency of these themes, along with example comments, is presented in the tables below.

### 6.2.3.1 Participant Assessment of the Challenges of Multi-Tasking

In the first question, the participants were asked if they found the control task challenging. 42% of the participants found the control task challenging, and 42% of the participants did not find it challenging. However, 17% of the participants reported that it depended on the traffic density. Participants also made further explanation about aspects of challenges in the control task. Their explanations are summarized and listed below in Table 6.11.

**Table 6.11: Aspects of the control task participants found challenging**

<b>Challenges</b>	<b>Percentage of comments</b>
Gaining situation awareness of the aircraft	22%
Keeping track of the aircraft all over the radar map	22%
The increase of the number of aircraft	22%
Avoiding negative incidents	11%
Multitasking	11%
Different speed of aircraft	6%
Locating targets	6%

A second question asked about the difficultness of handling the control task and the communication task at the same time. 33% of the participants claimed that it was difficult to handle both tasks at the same time. Out of the 33% participants, a few of them explained the factors that contributed to the difficulty of handling both tasks. Their comments are summarized and listed below in Table 6.12.

**Table 6.12: Factors contributing to the difficulty of handling the control task and the communication task at the same time**

<b>Factors</b>	<b>Percentage of comments</b>
Locating sector buttons on WAIT to make calls	25%
Distraction caused by incoming calls although they were helpful sometimes	13%
Gaining situation awareness of the aircraft	13%
Locating targets on the radar screen	13%
Multitasking	13%
The increase of the number of aircraft	13%
Un-clarity of aircraft data-tag on the radar screen	13%

In a separate question, participants were provided with some potential factors that were hypothesized for creating difficulty in performing the task and participants were asked whether they agreed with the statements or not. The factors were the following:

- a. Interfaces were confusing?
- b. Too many aircraft?
- c. Instructions were confusing?
- d. I did not understand the task!

The following subsections summarize the comments made by the participants for each factor

- a. ***Interfaces were confusing?*** 75% of the participants did not find the interfaces confusing, 17% reported that they were confusing, and 8% did not provide a specific answer. Only four participants expressed themselves regarding this point. For example, a participant mentioned that the sector buttons needed re-arrangement, and that they required more time to get used to them. Also, one of the participants found that some provided buttons in all the communication interfaces (“End Call,” “Rx,” and “Tx”) were unused. Another participant did not find that the interfaces differed from one another.

- b. Too many aircraft?** Most of the participants agreed that this factor affected their performance negatively. Two of them pointed out that they were affected by the number of aircraft with respect to the time. To illustrate, one said that the high number of aircraft was obvious toward the end, and the other one said that it would be acceptable if the aircraft increased gradually, but it was difficult because they increased suddenly. Another participant argued that it was not about the number of aircraft at a time but about the complexity of the situation.
- c. Instructions were confusing?** 75% of the participant showed that the instructions were not confusing; however, they made comments about the instructions they received. For the participants who explained their answers, their comments are summarized and listed below in Table 6.13. It is interesting to note how many of the aspects listed in the table refer to the distraction effects of interruptions as an answer to a question asking about the clarity of the instructions provided as part of the experiment.

**Table 6.13: Aspects that made instructions confusing**

Aspects	Percentage of comments
Locating targets that were mentioned in the instruction on the radar map immediately	25%
Receiving calls about pointless/meaningless questions	25%
Handling repeated calls	13%
Incoming calls occurring in III-times	13%
Multitasking	13%
Needing more time to perform or process the task	13%

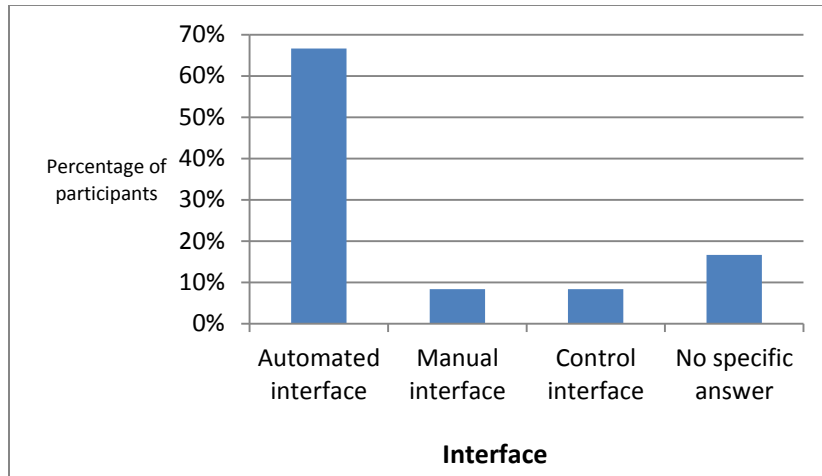
- d. I did not understand the task?** All 12 participants felt that they understood the task. However, some of them showed that sometimes it took time to understand a task. There were several factors contributed to slow understanding, such as the increase of the number of

aircraft, multitasking, problems in remembering what each direction of the map is, and the need to make immediate responses.

#### 6.2.3.2 Interface Comparisons and Comments

In order to delve more deeply into participant's perceptions of the different interfaces, participants were asked in the interviews several questions comparing the different interfaces. Participants were asked "Which interface did you find most helpful for communicating?" The overwhelming preference for the Automated interface can be seen in Figure 6.13 and Table 6.14.





**Figure 6.13:** “Which interface did you find most helpful for communicating?” (in percentage)

**Table 6.14:** “Which interface did you find most helpful for communicating?” (# of participants)

	Automated interface	Manual interface	Basic interface	No specific answer
Number of Participants	8*	1	1	2

\* indicates the mode for each condition

Comments collected for each interface on why participants liked or disliked the interface included:

- a. **Control Interface.** The only participant who preferred the Control interface stated that they liked it for being simple and convenient. Another participant stated that it has one positive aspect although it was not his preferred interface, saying “In Control interface, you don’t have the developed features; however, I liked that you didn’t have to consider your availability, yet I can see how important it is.” Other participants who found the Control interface less preferable commented, saying “With no availability indicator, all random/pointless calls are transferred.” The other one said: “It was hard.”

**b. Manual Interface.** The only participant who preferred the Manual interface for communicating commented that the personal judgment of availability is the best indicator of availability. One of the participants who did not provide a specific answer for the preferred interface pointed out that the Manual as well as the Automated interface showed more specific details about availability, and that lead to receiving less volume of calls. The aspects that deterred the participants from selecting the Manual interface as the best interface for communication are summarized and listed below in Table 6.15.

**Table 6.15: Problems with the Manual interface**

<b>Problems</b>	<b>Percentage of comments</b>
One more task to think about	33%
Difficult to judge personal availability	17%
Inapplicable when dealing with lots of aircraft	17%
Perceiving unavailability of other controllers causes distraction	17%
The inability of changing availability allows for all random/pointless calls to be transferred	17%

One participant pointed to what he named as “incentive” (the WAIT score that was applied only in the Manual interface) by saying “With no incentive provided to make the availability to low in Manual, I would say the Manual interface was the best one.” As mentioned in the previous chapter, the score was added to the Manual interface to deter participants from setting-up their availability as Red (unavailable) all the time; the least points were assigned to the Red level (unavailable) while highest points were assigned to the Green availability level (available).

c. **Automated interface.** As stated, most of the participants showed affinity for the Automated interface. The reasons they expressed this are categorized as common factors and are listed in Table 6.16.

**Table 6.16: Reasons that made the participants prefer the Automatic interface**

<b>Reasons</b>	<b>Percentage of comments</b>
One less task to worry about	25%
Leads to less volume of calls	17%
Provides the functionality of deciding the urgency of outgoing calls	17%
I don't have to do anything with it	8%
No concerns about finding time to set-up the availability	8%
Prioritizes the safety of people on aircraft over any interest the user has	8%
The alarm sound helped in gaining situation awareness of the aircraft in one's sector	8%
The number of aircraft is a very good predictor of availability	8%

On the contrary, the participant who disliked the Automated interface and preferred the Control interface over mentioned the following reasons:

- It was distracting. The distraction occurs when:
  - The sound of changes in “My Availability” indicator plays
  - Perceiving the unavailability of other controllers
- The number of aircraft in one's sector is not an efficient representation of the availability

### 6.2.3.3 Using WAIT Features

In the next question, participants were asked if they ever used the provided features in the Manual and the Automatic conditions intentionally. They were asked specifically about setting-up the “My Availability” indicator manually in the Manual interface. Also, they were asked if they used “Other controllers’ availability” and specified the urgency level of their outgoing calls in both Manual and Automated interfaces.

The next sub-sections discuss the comments collected for each feature on why used or unused.

- a. My availability.** Half of the participants used this feature either only once or several times throughout the Manual trial. The explanations that participants made for the reasons of not using this feature continuously throughout the trial are summarized and listed below in Table 6.17.

**Table 6.17: Reasons for not changing availability manually in the Manual interface**

<b>Reasons</b>	<b>Percentage of comments</b>
Feeling available all the time	21%
Hard to find a time to change it	21%
Not as important as other tasks	21%
The score incentive deterred from changing the availability	21%
One more task to manage	7%
The desire to receive all the calls	7%

One of the participants who liked this feature, but Manual interface was not her preferred interface commented on this question by saying, “It was in the back of my mind. I [kept]

saying that I need to switch it, so I won't be getting so many calls, but I only changed it few times because I was so stressed." Likewise, another participant reported "It is helpful, but I couldn't make it."

- b. *Other controllers' availability.*** Almost all the participants (92%) reported that they used this feature; however, 55% of them agreed that looking at other controllers availability was ignored when their outgoing call is urgent. In contrast, a participant reported that he ignored looking at other controller's availability when making non-urgent calls. He said "[In such a case], I didn't expect to receive an answer." However, a participant stated that her call was non-urgent, and when she saw that the availability of the controller was Red, she ended her call. An important point reported by one participant regarding saving time when making calls is "Initially, I was thinking of making non-urgent calls to see the controller availability then change it to urgent, but then I realized that I have to make it happen as urgent [from the beginning, regardless of the controller's availability level]."
- c. *Urgency-level of calls.*** Most of the participants (83%) used the urgency level feature intentionally. A participant brought up a point about which side of the call (interrupter vs interruptee) benefits from the urgency level. He said "It depend[s] on someone's judgment because what is important to someone is not necessary important to the other person". He also provided a suggestion to solve this issue, which is creating a standard between controllers of what is considered urgent and what is not. Another participant reported that he intentionally abused this feature by making only urgent calls in order to force the other controllers to answer his calls.

#### 6.2.3.4 Interface Improvements.

The last two interview questions were about providing comments or suggestions for the usability of the interfaces or for WAIT features

- a. Usability of the interfaces.* Seven out of twelve participants made some suggestions for a better WAIT user interface. The suggestions are summarized and listed below in Table 6.18.

**Table 6.18: Suggestions about the usability of the interfaces**

<b>Suggestions</b>	<b>Percentage of comments</b>
Re-arrange the controller buttons	43%
Use hotkeys on keyboard instead of the mouse to keep one's eyes focused on the screens	29%
Make a different formatting for each urgency level on the buttons sub-divisions	14%
Remove controllers availability panel from the screen while not active to reduce distraction	14%

- b. WAIT Features.* The suggestions that six of the participants provided for improvement to the interruption management features are also summarized and listed below in Table 6.19. Additionally, some participants made positive comments about the developed features. A participant added his opinion by saying “Conceptually, it’s a good idea.” Another participant said “They were excellent.” Moreover, a participant reported that “The features were sufficient for the purpose.”

**Table 6.19: Suggestions about the WAIT features**

<b>Suggestions</b>	<b>Percentage of comments</b>
Add urgency level to the incoming calls	33%
Combine the Automated interface and Manual interface conditions in one interface and allow users to switch between them based on their needs	33%
Make other controllers availability visible without clicking their buttons	17%
Place "Controller Availability" indicator in the center of the sectors buttons	17%

#### 6.2.3.5 Improvements and Suggestions about the Study

Most of the suggestions participants described would not be needed if the participants had prior ATC experience. Many of the points that the participants brought up are very familiar with the air traffic controllers. The suggestions were mostly about adding cues to the radar map screen to help gaining situation awareness, such as adding cues to aircraft when they deviate from their pre-set lines as a reminder to re-direct these aircraft back. Additionally, adding cues to targets in general on the radar map when other controllers refer to them in incoming calls.

One of the major issues that many participants reported is that the radar score was not affected when aircraft were not rerouted back to their pre-set lines, although the participants were instructed in the training sessions to perform this task as one of their responsibilities. Observing that fact during the trials made some of the participants ignore rerouting the aircraft to their lines and concentrate only on getting aircraft away from negative incidents on the radar map, such as critical weather areas and aircraft collision situations. Subsequently, this would create imbalanced goals amongst the participants and would heavily affect their radar scores.

## **6.3 Discussion**

The results presented above illustrate the wide range of observed data collected about both the WAIT interface design and the value of the interruption management features. The following subsections discuss the interpretations and significance of the results and synthesize the findings across the distinct data sources presented above.

### **6.3.1 Desirability of an Interruption Management Tool**

#### **6.3.1.1 Preference for WAIT (in general)**

Overall, participants showed preference to using WAIT in general over using the Control interface. For example, both Automated and Manual interfaces had better overall performance than the Control interface as shown by the participants' self-rating data (Figure 6.5) and the participant objective performance scores (Figure 6.1) as compared to the Control condition. Moreover, the results showed a trend of reduced distraction effects due to interruptions from other controllers in the conditions with an interruption management tool (Figure 6.2). Furthermore, participants did not report substantive challenges related to using WAIT except for a minor aspect that is related to the participants lacking experience in ATC multitasking.

The following sub-sections describe the results for each WAIT feature against having no features in the Control interface.

#### **6.3.1.2 Desirability of an Availability Feature**

The results suggest there is a clear desire of the participants for an availability feature as part of performing this type of collaborative task. In all interface conditions, over half of the participants reported that it was moderately to extremely important to have the ability to convey one's level of



availability (Figure 6.7). The following discusses the desirability of specific parts of the availability feature.

### *My availability*

The comments described in Figure 6.13 showed that with no availability indicator (as in the Control interface), participants realized that they receive all types of calls, even the ones that are pointless. This is obviously less desirable in a high peak busy time or when dealing with emergencies. This implies that the availability indicator in both Automated and Manual interfaces was beneficial to the participants to manage interruptions.

Additional evidence that supported the need for the availability feature was mentioned in participants' comments when asked to select the interface they found most helpful for communicating. For instance, in the Control interface, one participant said: "In Control interface, you don't have the developed features; however, I liked that you didn't have to consider your availability, yet I can see how important it is." Also, other evidence is noted in the participants' comments when they were asked to provide examples of the techniques they used to convey their level of availability other than the provided features. For example, in the Control interface, some said "By conveying the availability verbally." Indeed, it shows that if the controller interrupters were aware of participants' availability, it would change their behavior when initiating calls and that will save the interruptee's time from informing the interrupter of their availability verbally. Finally, as seen in Figure 6.11, 42% of participants took advantage of the ability to set their own availability and reported that they intentionally set their own availability when this feature was available in the Manual interface condition. The results support the conclusion that providing a "My availability" feature in an interruption management tool is desirable and worthy of further research.

### *Other controllers availability*

Almost all participants (92%) reported making use of the other controller's availability in the conditions where this feature was present. Participants observed the other controllers' availability when participants needed to call them and understand what the availability level color means in terms of controller's availability; however, their reaction towards "other controller availability" was varied:

- If the participant's call is urgent, looking at the controller interruptee's availability is ignored. The participant in this case is only concerned about the urgent situation that he/she wants to solve, and they know that the controller will answer the call regardless of the controller's status because the call was initiated as urgent. This is desirable and indicates that the presence of the availability feature did not introduce new types of errors based on the suppression of communicating critical information.
- If the participant's call is non-urgent, at least one participant actively changed their behaviors based on the other controller's availability. It was observed that if the other controller's availability was unavailable (Red), the participant would sometimes end the call immediately. It is thought that this reflects the participant thinking that the issue of the call was not very important or needing an urgent response; it could also be participants knowing that the controller may not answer the call, so it was better to end the call and focus on other tasks instead of waiting without a guaranteed response. This is indicative of the type of behaviors that the WAIT tool was designed to support. There was also another participant who reported ignoring the other controller's availability when she makes a non-urgent call. An anecdotal example to this case is the comment she made "[If they really are too busy], I don't expect an

answer.” Therefore, the participant did not shift her gaze to the availability panel in order to figure out how available the controller is.

### 6.3.1.3 Desirability of an Urgency Feature

Participants’ subjective ratings on the difficulty level of communicating the urgency of calls to the other controllers showed that, in general, the WAIT (Manual and Automated) urgency level feature made it easier for the participants to convey the urgency of their calls.

Some other evidence that supported the need for urgency level feature were mentioned in the comments when participants were asked to provide examples of techniques that they used to show the urgency of outgoing calls other than the provided tool feature; one of the comments was “[To] convey the reason of urgency (e.g. crash).” Participants were also asked to provide examples of the techniques they used to convey their level of availability other than the provided feature. One of the comments made was “Ignore giving answers to unimportant questions.” Both examples are relevant to the importance of the urgency level. They clearly show that if the participants had a way to know the importance or urgency level of the call before answering it, it would save them the time spent deciding whether to respond to these calls or reprioritize the tasks at hand. The first example means that if they had an indicator to present their level of availability as un-available, they wouldn’t receive unimportant questions/calls. Furthermore, a participant provided an example of a technique he used to convey his level of availability other than the provided feature. He said that he would continue speaking in an active call and ignore answering the incoming call that occurs at the same time. This would imply that knowing the urgency level of a call would help in making controllers less stressed if they knew what level of urgency the call they missed was or to decide if they should end the active

call if it was less urgent. Related to the above results, most of the participants (92%) reported that they used this feature intentionally.

## **6.3.2 Evaluation of Implemented Features**

### **6.3.2.1 Overall Preference for Automated interface**

As a whole, the results point to a preference of participants for the Automated interface. This preference is observed in the objective measures of performance (Figure 6.1) as well as in the participants' self-ratings of overall performance in the three interfaces (Figure 6.5). It showed a reduction in the distraction effects of other controllers (Figure 6.2), and it was perceived (unsurprisingly) as the easiest technique for conveying one's availability to other controllers (Figure 6.8). Participants also found it the most helpful for managing interruptions (Figure 6.9) and for communicating (Figure 6.13). These results indicate that the Automated interface is a promising direction that should be examined in more detail in future studies.

The preference for the Automated interface appears to be due to several reasons. In the Automated condition, participants do not have the task of explicitly setting their availability; something that they are required to do in the Manual condition but did not do for a variety of reasons (see Table 6.17). This additional "task overhead" was a common challenge identified in the Manual interface condition, and participants made references to the extra task associated with the Manual condition in their responses to multiple questions (Table 6.9, Table 6.10, Table 6.15, Table 6.16, and Table 6.17). This could make automated decision support tools more appealing, particularly those that reduce the task demands on the participant.

### 6.3.2.2 Feedback on Implementation of Specific Features

#### *Feedback on availability feature*

Most of the participants, as seen in Figure 6.7, showed positive ratings on the importance of conveying the availability level for the Automated interface over the Manual interface. As mentioned earlier, results were similar for Automated and Control interfaces. It is reasoned that participants did not like having to perform tasks that would add to their workload as the task of setting-up the availability level that was required in the Manual interface, while it was automatically set-up in the Automated interface or not existing in the Control interface.

In the results of Figure 6.8, where participants were asked to rate the difficulty level of conveying the availability level to other controllers in the different interfaces, they showed that it was much easier to convey it in the Automated interface. The automated availability level conveyed the availability of participants based on the number of aircraft in the sector that they are in charge of.

Furthermore, participants were asked about the most helpful availability feature for managing interruptions. 75% of the participants showed that the Automated feature was more preferable than the manual one (Figure 6.9). This implies that in time-critical environments, operators tend to use features that facilitate their work and at the same time help them focus on the tasks at hand. As shown in Table 6.9, this is reflective of the feedback from participants' preference of the Automated feature. Some of the comments were: "It requires less workload," "Saves the time spent in cognitive work," "Provides the ability to focus on control task," and "Number of aircraft is a good indicator of busyness." Likewise, the participants showed that the availability feature in the Automated interface was identified as easier to use over Manual interface in managing interruptions (see Figure 6.10). As

a matter of fact, participants were looking for simplicity and convenience, which is why the Automated was preferred over the Manual interface.

### *Feedback on urgency feature*

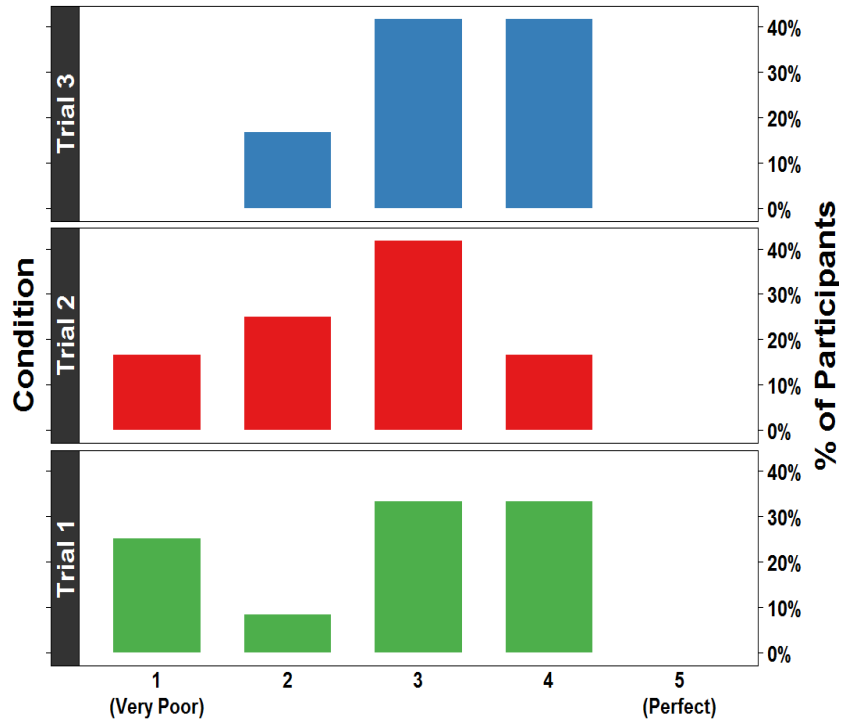
The results presented in Figure 6.3 show that participants expressed substantive preference for the Manual over the Automated interface in producing less distraction effect of interruptions to other controllers (outgoing calls). This could be reasoned by observing that the participants were not able to take advantage of the availability feature provided in Manual, and consequently, it didn't affect the volume of incoming calls for these participants. The reasons of the variation of distraction effect for incoming and outgoing calls could be because outgoing calls that participants have to make are always about requesting changes to aircraft heading or speed in order to avoid negative incidents. Since about half of the participants did not change their availability in Manual interface, they subsequently received all calls from the controllers. Originally, two thirds of the other controllers' calls were not for urgent matters (see Table 5.5), and part of the participants' tasks was requiring them to deal with matters even if they did not receive calls about them. In this way, participants got rid of many calls that they had to make when they did not change their availability and consequently responded to all calls.

### **6.3.3 Experimental Design Considerations (Learning Effects and Scenario Equivalency)**

In order to assess the effectiveness of the experimental design and to check if the training provided to participants was sufficient, checks were made of participant performance as a function of both trial number and scenario.

Having the participants perform the required tasks in three sequential trials might have led them to learn from their mistakes and develop new strategies. In fact, one participant's feedback appeared to point to this statement when she said "When I'm doing the three trials, I'm trying to improve and do better each time, so I kind have a different strategy." As they were going through multiple trials, participants may have learned to predict the behavior of the recurring events. To illustrate, one participant when once was asked by a controller for his permission ("yes" or "no") to re-direct an aircraft into his sector (in the second and third trial), he immediately said "yes" without thinking about it although in each trial, the call was from a different sector-controller interrupter, regarding a different aircraft number and airline, and the upcoming event of the message took place in different sectors. He seemingly created a mental model of what is expected in this type of call.

In order to investigate the possible learning effects, the data gathered on participants' overall performance was analyzed again based on the order of the trials for each participant, as seen below in Figure 6.14 and Table 6.20. Figure 6.14 shows the distribution of self-reported overall performance (e.g. same data as presented in Figure 6.5 above) as a function of "trial number." Visual inspection of the graph shows that there are no substantive differences in the overall distribution of self-assessed performance scales as a function of trial number. There is an indication that the percentage of people feeling they performed very poorly decreased from trial one to trial three, however, this is not matched with corresponding changes at other rating points. The objective participant performance scores do show an interesting trial effect; as can be seen in Figure 6.15, performance was almost 100% worse in Trial 2 as compared to Trials 1 and 3. Therefore, the data collected shows that the training appears to have been sufficient, and that and there is no evidence of learning effect.



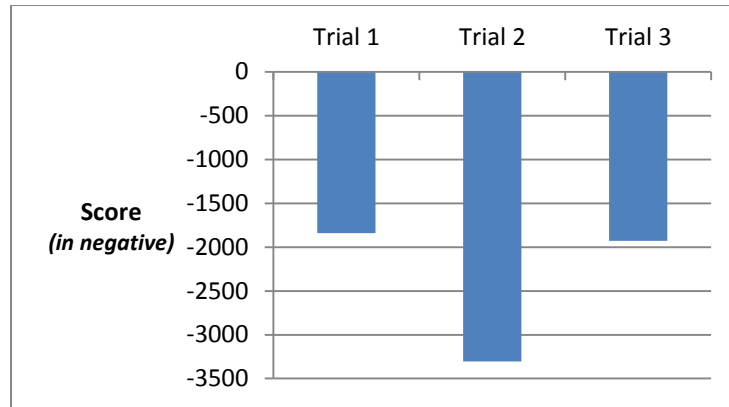
**Figure 6.14: Overall Performance based on trial order (in percentage)**

**Table 6.20: Overall Performance based on trial order (# of participants)**

	1 (Very Poor)	2	3	4	5 (Perfect)
● Trial 1	3	1	4*	4*	0
● Trial 2	2	3	5*	2	0
● Trial 3	0	2	5*	5*	0

\* indicates the mode for each condition





**Figure 6.15: Average participants' radar screen score as a function of trial number**

A second experimental design consideration was making sure that the air traffic scenarios used were as equivalent as possible, yet not to the point of being recognizable by participants. Similar to checking for a learning effect, participant self-reported performance ratings were examined to determine if the air traffic scenario had an effect separate from the WAIT interface condition.

Figure 6.16 and Table 6.21 present the distribution and the number of participants, respectively, for self-reported performance scores for each of the three air traffic scenarios (see scenario description in sub-section 5.1.4). As can be seen by visual inspection, the choice of air traffic scenario did not appear to make a substantive difference in the distribution of self-reported performance of the participants. However, Scenario 1 does appear to have led to an increased perception of very low performance (Figure 6.16 and Table 6.21). In order to check if the traffic scenarios were of approximately equal difficulty, Figure 6.17 plots the average performance score for each scenario. Here, there is an observable ~ 15% difference between Scenario 1 and Scenarios 2 and 3, consistent with the self-reported perceptions of performance. However, these differences do not appear to be dramatic. Based on both sets of data, it appears that the scenarios did not have substantive impacts on

overall performance, and the techniques used to create approximately equivalent traffic scenarios were effective.

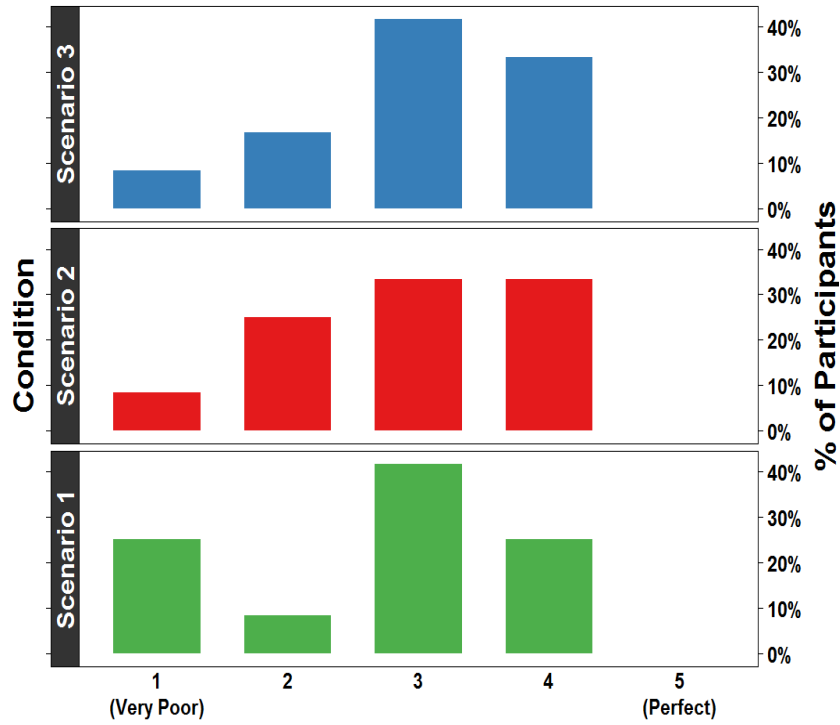
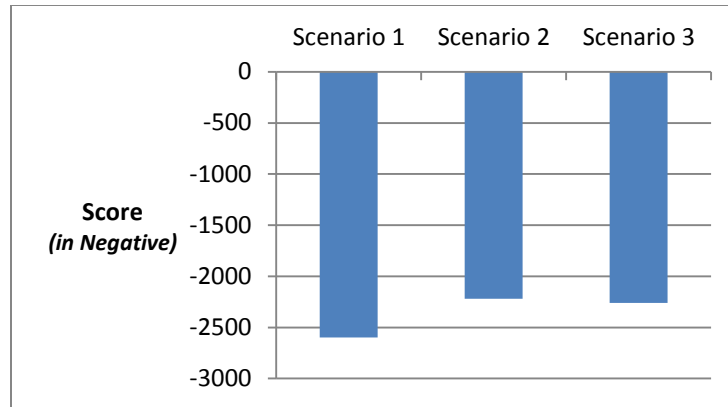


Figure 6.16: Overall Performance based on scenario order (in percentage)

Table 6.21: Overall Performance based on scenario order (# of participants)

	1 (Very Poor)	2	3	4	5 (Perfect)
● Scenario 1	3	1	5*	3	0
● Scenario 2	1	3	4*	4*	0
● Scenario 3	1	2	5*	4	0

\* indicates the mode for each condition



**Figure 6.17: Participants' radar screen score average as a function of scenario number**

## 6.4 Lessons Learned: Implications for Interruptions Research

The following subsections discuss the key challenges encountered during the experimental evaluation, the lessons learned, and the implications for other researchers conducting similar experiments on interruption effects.

### 6.4.1 Task Design

The goal of the experiment was to begin exploring how interruption management features could be incorporated into the tools available in complex real-time collaboration environments like air traffic control. An experimental design challenge was developing a task environment that is sufficiently representative of real world operations so that the results have validity, but which also provides the controls and constraints to enable researchers to experimentally manipulate the conditions and introduce interruptions in a controlled, repeatable manner.

In particular, an important challenge was developing task environments where it would be natural for participants to want and/or need to take advantage of the interruption awareness functionality. Key to

this was ensuring that interaction took place with another human, or confederate; this replicates real-world collaborative environments, where interruptions are dynamic, messy, and social. A challenge with using synthetic or computer based interruptions is the loss of social pressure on the participant; the task scenario becomes nothing more than a game with only a computer's feelings being hurt if parts of the task are ignored. By introducing the human element it is thought that more insight into participant use of tools like WAIT will be found. Using real people to act as the other communicators in the experiment creates a more realistic environment which will influence the behavior of the participant (Sasangohar, 2009).

A second key aspect of the task design was developing realistic, context-accurate types of interruptions to create circumstances where there are obvious benefits to participant use of the tool for the task at hand. If interruptions are contrived or unrelated to the task, they risk becoming an annoyance and distraction only. This may critically miss the fact that in many cases, interruptions provide benefits in the form of new or updated information that is relevant to the primary task. In the case of the current experiment, knowledge of ATC operations was used to develop plausible information requests, trajectory change requests, and other types of communications from the other controllers and pilots in the study. This represented a balance between having the ability to control the timing and type of communications that would generate an interruption, and having the interruptions be meaningful and well-integrated into the participant's task.

A third key task design decision was developing an appropriate environment for implementing the WAIT tool. There are many existing ATC simulations; however, none were identified that could meet the many requirements for this type of research study. The simulation needed to provide experimenters control over the traffic trajectories to assure equivalency between the level of workload

and type of conflicts each participant must resolve in the different experimental conditions. In addition, most simulations require the controller to interact with mouse and keyboard to provide commands to aircraft; while ATC is moving in this direction with the adoption of Controller-Pilot-Data-Link Communications (“CPDLC”) functionality, this adds to the training complexity of the task for non-expert participants (Nolan, 2011, p.611). An ATC simulation that supports networked operations has the advantage of allowing for a co-experimenter who has been trained and is very familiar with entering keyboard commands. This in turn allows participants to simply use their voice to give commands and instructions.

Moreover, many simulations are either too simple, more akin to a game without the necessary interactivity between controllers at airspace boundaries, or too complex, requiring detailed knowledge of air traffic control procedures and operations. Finally, the simulation environment needs to have the flexibility to adapt to the experimental needs. For example, the display shown to the participants includes surrounding sectors, which is very infrequent in most existing simulations. However, it is critical for matching existing real-life practices and for creating the interactions between controllers that leads to interruptions; in addition, it is very valuable to be able to have the ability to derive certain data from the ATC simulation for logging and analysis purposes.

#### **6.4.2 Interruption Design**

Designing effective and repeatable interruptions is challenging. Interruption tasks should be distracting enough that they constitute a genuine disruption of a participant’s work. However, it is also important for data collection purposes to have the same number and type of interruptions in each experimental condition. This is particularly challenging in dynamic environments, such as ATC,

where participant actions change how the traffic situation evolves. Ensuring that all participants experience exactly the same conditions is impossible.

During initial pilot tests, it was found that participants tended to lose situation awareness of the availability of other controllers. Also, sometimes, urgency levels of calls were not assigned by the participants intentionally. This indicates that the interruption tasks were extremely distracting.

This has important implications for study design; in particular, the differences between conditions should be expected to be fairly large. Subtle, small differences between experimental conditions will be very difficult to elicit as they will tend to be masked by the large amount of noise that is inevitably introduced by unintended differences in the conditions experienced by different participants.

#### **6.4.3 Participants' ATC Experience**

Air traffic controllers are trained to monitor their different screens periodically. Unfortunately, fully trained air traffic controllers are often not available as participants, requiring the use of participants with little to no formal training or experience with ATC. A consequence of this, identified in preliminary pilot tests, is that non-expert participants tended to focus almost solely on the ATC radar display and to pay relatively little attention to the WAIT screen. In these cases, several important events related to the WAIT tool were missed. This process of selecting inappropriate elements of the environment and ignoring other important elements is called “selective attention” (Wickens & Hollands, 2000). This is because people tend to get more involved in motivated contexts. In the context of the experiment, it appeared that participants were being motivated by a performance score shown in the top of the radar screen. While providing feedback can be a valuable way of motivating participants, in this case, it appears participants became pre-occupied by the winning goal and less concerned about using the developed new features in the WAIT screen. As a result, an additional

communication scoring system was added to the WAIT screen to provide cues that would assist with attention balance. Moreover, sound alerts were added to critical communication events to enhance participants' attention to the WAIT screen. For instance, a ringing sound was added when a call occurs, and a sound alert was added to the availability changes in the Automated interface to indicate the automatic change of availability levels.

#### **6.4.4 Tools to Support Data Analysis**

A final lesson learned is the importance of early and active consideration of the performance data that should be collected from within a simulation system. Active pre-planning of data to be logged can help prevent the loss through non-collection of important data parameters. Careful consideration should be given to what kind of performance and behavior data would support follow up analysis of findings and insights developed from questionnaires and interviews. Establishing a good sound system that will allow for a clear recording of the experimental team and the participants voice is very important. For example, for future work, more aspects of the study might be investigated, so it would be very useful for future researchers in the same topic if they have access to all important data. Also, some data that does not seem to be relevant to the analysis might actually reveal unexpected interesting results.

#### **6.4.5 Specific Interface Improvements**

Participant feedback also highlighted areas for improvement of the WAIT interface. Among the factors that made it difficult to handle the control task and communications, the highest percentage was "locating sector buttons on WAIT to make calls." Even though this factor was directly about WAIT, it is not considered as a crucial factor because, as mentioned, the participants do not have previous experience using this tool. As using any tool in our daily life, it might take time to get used

to it. Some participants confessed that it was hard in the beginning to remember where each sector is, however in the following trials, this process occurred more naturally. Also, this could be argued that by knowing that in ATC, each sector might have different configuration for their VSCS screens, so there was no standard position guidelines for the buttons when they were designed for the experiment; we were expecting comments about this factor during the design process. Additionally, the use of a mouse to navigate between controller channels might contribute to this problem, as stated by 17% of the participants who commented on this issue regarding the usability of WAIT interface. The problem might be solved if they were using their fingers on touch screens directly to the desired sector channel, as in the real world.

In the Interviews section, participants provided suggestion to improve the WAIT interface. Some participants suggested not limiting the urgency level feature to outgoing calls only, but adding it to incoming calls as well. This was partially implemented during the experiment and interface design process; however, it was ultimately decided to be removed in order to keep the scope of the experiment manageable.

The results and observations clearly show that one of the challenges participants encountered with the interfaces was the extra task load that the interruption tool presented. Multiple participants commented that the Manual and Automated interface conditions required an additional task (that of investigating the interruptee's availability before proceeding with a call) and that this represented a distraction and/or barrier to effectively performing their communication task. To address this problem, it is recommended that future developments of the WAIT interface consider having each controller sector button attached to an availability panel that is active all the time, without the need to make calls to controllers to see their availability level. An alternative is to explore a suggestion



provided by another participant: the "Controller Availability" indicator would be placed in the center of the sectors buttons to be reached more conveniently (in this way, it will not be active unless the controller channel is demanded). Another suggestion was to hide the non-active panel until the controller channel is demanded. In order to make the suitable configuration, the distraction effect caused by each suggestion should be studied.

## **6.5 Conclusions**

### **6.5.1 Presence of an Interruption Management Tool Improved Performance**

As a whole, participants showed interest in having a tool that would help them manage interruptions, and the presence of such a tool improved their performance. Objective performance data on the ATC task showed higher scores for both conditions with an interruption tool (Automated/Manual) as compared to the Control condition (Figure 6.1). The self-rating data of participants' overall performance in both conditions with an interruption tool was better than in the Control interface condition (Figure 6.5). The results showed a trend of reduced distraction effects due to interruptions from other controllers in the conditions with an interruption management tool (Figure 6.2). The results suggest interruption management tools in this context offer potential and are worthy of further study and refinement with a larger group of subject-matter expert participants.

### **6.5.2 Simple Interfaces for an Interruption Management Tool Were Preferred**

Despite the positive effects of the interruption management tools, participant comments also indicated that the simplicity of the Control interface condition was appreciated. Specifically, the lack of a need for cognitive energy to be spent on setting their own, or interpreting another controller's availability was seen as a strength of the Control condition. This suggests to future tool designers that it is

important to develop interruption management tools with as little task overhead as possible; this can be achieved by keeping interfaces as simple as possible.

### **6.5.3 Further Study Should Start with Automated Controller Availability**

The results are consistent with an Automated setting of controller availability being more likely to be operationally acceptable than a Manual setting of controller availability. The Automated interface was identified as being the most helpful for managing interruptions (Figure 6.9) and the Automated interface was identified as being the most helpful for communicating (Figure 6.13). There is some indication that the Automated condition reduced the distraction effect of interruptions from other controllers as compared to the Manual condition (Figure 6.2). Additionally, in the Manual condition, participants reported that having to set their availability added to the number of tasks that they had to track (Table 6.10, Table 6.15, Table 6.16). Participant behavior was consistent with participants forgetting to set their availability and being too occupied with other parts of the task to set their availability (Table 6.17). The Automated availability feature allowed participants to focus on their work while still providing the opportunity to have incoming interruptions filtered by their availability. For these reasons, further study of interruption management tools, including the Automated availability setting features, appear to be the most promising.

### **6.5.4 Further Work Should Consider Alternatives to the Number of Aircraft as the Basis for Automated Availability**

Participant opinions varied on the appropriateness of the number of aircraft in one's sector as the basis for determining a controller's availability in the Automated condition. Some participants felt the number of aircraft was inappropriate and could be misleading, as a controller may not be busy even with large numbers of aircraft. Others felt that the number of aircraft was a good indicator of

availability. Further work is needed to examine specifically the potential basis used to determine availability in an Automated approach. It should consider alternatives such as dynamic density (Laudeman et al., 1998; Smith et al., 1998) or other potential measures that can be automated, like the amount of time spent talking on a radio frequency.

### **6.5.5 Urgency Feature Requires Independent Study to Address Unique Concerns**

As noted above, the presence of the urgency feature in the two WAIT conditions (Automated and Manual) was associated with improved performance and reduced distractions from other controllers. Generally, participants did not report any major problems with using the urgency feature. However, participant's comments did highlight specific concerns about the potential negative effects of introducing urgency features that would warrant further, targeted investigation in the future.

Similar to controller comments during the Participatory Design exercise (Chapter 4) a concern was raised about the abuse of the urgency feature by always using the "Urgent" level to force others to respond to a call regardless of the situation. Another issue identified was the time and/or effort (even if very low) required for a participant to decide which level should be selected to convey the urgency level. This could slightly delay communications. Determining whether this is a substantial concern or one that fades with practice, experience and/or training should be determined in future work. Finally, there are interesting social considerations (e.g. long term reputation) that might affect the use of this feature that could not be addressed in the present study; given these unique concerns further study specifically on the urgency feature appears warranted.

## Chapter 7

### Findings and Future Work

Developing appropriate situational awareness cues and understanding how they affect the performance of system users was an important piece of this research. With the development of WAIT that provides such cues, the thesis examined ways to support interruption management while reducing the negative impact of interruption on operators in complex work environment such as air traffic control. The collected observations were analyzed to determine how the developed features included or excluded in three interfaces impacted participants' interruption management. This chapter reviews the research findings, targeted research objectives, and future work.

#### 7.1 Research Findings

Stated at the beginning of the thesis in Chapter 1, this thesis asks: “In time-critical, dynamic, and collaborative environments, like ATC, what awareness-assisting techniques would allow for more efficient and appropriate interruptions while at the same time mitigating the negative effects of interruptions?”

To address this research question, three objectives, which this thesis was structured around, were investigated. The objectives are restated below, and it is discussed how they were achieved.

*Objective 1 - Identify existing techniques that the controllers use to gain interruption situation awareness and identify the factors that cause inefficient interruption management.*

The first research objective was addressed by reviewing the literature as detailed in Chapter 2 and the data collected from field observations and questionnaires as described in Chapter 3. The concept of

situation awareness is very relevant to the concept of interruption, and provides a basis for suggesting potential improvements regarding interruptions management in the current ATC communication system. Field observation in a real ATC environment collected through site visits and interviews with subject-matter experts showed that controllers try to prioritize their tasks in a way to avoid being involved in communication tasks that are of less importance or urgency level than the tasks at hand. Observations relevant to the design of interruption tools included the identification of factors that influence the controllers' perception of the busyness of another controller, including techniques like having a "muted" radio transceiver present to be able to determine whether the other controller is communicating with pilots.

Based on the most important aspects identified through the process of achieving Objective 1, two main questions regarding controller-controller communication using VSCS were investigated to identify opportunities to improve interruption management for controllers. The result was incorporated into the initial prototypes of a communication display. This leads to the second objective, which was to develop new features supporting interruption situation awareness that could be incorporated into existing controller communications screens.

*Objective 2 - Investigate potential improvements to the developed design of controllers' communication screens that would help support interruption awareness.*

From the literature review, as well as the field observations and questionnaires conducted for Objective 1, multiple interruption management tool prototypes were designed and then narrowed down to a specific number of designs. Eventually, the second objective was achieved by conducting interviews and "Participatory Design" sessions with subject-matter experts about the prototypes. Feedback about the initial prototype designs in terms of practicality and acceptability was obtained.

The results of this process were important as they resulted in insights that helped to create the refined features that were inserted into a display emulating existing communication screens, named the Working Awareness Interruption Tool (WAIT). Finally, two distinct interface designs were developed based on a very simplified existing version of VSCS ATC screens (as described in Chapter 4). The developed WAIT features allowed controllers to set their availability status manually or automatically and specify the urgency level for outgoing calls.

*Objective 3 - Evaluate revised versions of the developed features using a user based experimental methodology.*

Finally, the third objective of the thesis was addressed by conducting a laboratory experiment with 12 participants to evaluate the effectiveness of WAIT in mitigating the negative effects of interruptions. This was done by testing the participants' performance results among the three interfaces. The Control interface data was compared to the two different WAIT interfaces to observe the differences of handling interruptions with the existence of the new features (as described in Chapter 5 and Chapter 6).

The findings from the study suggest that providing controllers with indicators of availability and a way to specify the urgency level of their calls had value and should be considered for further development in the future. The results showed that using features provided in the WAIT interface affected the performance of participants positively. Specifically, considering the data collected across a range of measures, the study showed a clear advantage of the Automated interface over the Manual interface. This is observable in the data collected from objective performance scores (Figure 6.1), self-reported distraction effects of interruptions from other controllers (Figure 6.2), self-assessed performance (Figure 6.5) and preferred availability feature (Figure 6.9). The interface was identified

as being the most helpful for communicating with other controllers (Figure 6.13). Participants found that the Automated availability features was the most helpful and the easiest representation of availability.

The main aspect of WAIT interfaces that was preferred by most of the participants is the automaticity factor in the Automated interface that facilitated regulating interruptions and did not add to their work/cognitive load. Additionally, the results confirmed that operators in complex systems tend to get rid of any further steps or tasks, as possible, which was clearly shown in their responses towards using WAIT interfaces, and that is the reason the other variation of WAIT (Manual interface) was less preferable due to the additional task it required of the participant to perform in order to get benefit of the personal availability indicator.

## **7.2 Contributions**

While this is an early, exploratory investigation of interruption management tools, there are several contributions made by the work in this thesis. First, this work identified two examples of specific features (availability and urgency) to be designed into an interruption management tool specifically for the air traffic control domain. This work has also presented subject-matter expert feedback on interface implementations incorporating those features and identified potential implementations that would be impractical and unlikely to be supported in real-world operating environments. To the author's knowledge, the identification and development of these awareness features have not previously been investigated in tasks representative of the air traffic control domain.

A second contribution has been the evaluation of refined implementations of the features showing that the presence of interruption management features (e.g. WAIT) in an ATC-like task context improved participant performance and appeared to reduce the distraction effects of unwanted

interruptions. The evaluation also suggests that the Automated setting of availability is the more promising means of communicating availability. Based on the evaluation of the developed features, enhancements of the tool design have been identified and documented.

Finally, the research contributes to the development of techniques for evaluating complex phenomena like interruptions in technical and demanding domains like Air Traffic Control. The techniques developed for controlling and standardizing interruptions could be adapted by other researchers, as they represent an important balance between ensuring repeatability and consistency between participants and embracing and incorporating the richness and dynamics of real-world human-to-human communications. The techniques developed and presented in Chapter 5, as well as the lessons learned from implementing the complex experiment presented in Chapter 6, provide baseline steps and guidance for future researchers to conduct similar experiments in such a field.

### **7.3 Study limitations**

As in any study, there are a number of limitations associated with the research presented in this thesis. Some important limitations and their implications for the interpretation of the results of the research are discussed below.

#### **7.3.1 Limited Number of Participants**

An important limit on the generalizability of the findings from the experiment (Chapter 6) is the number of participants. Twelve participants provided a cross-section of responses but these responses might not be representative of the findings obtained with a larger sample. Notwithstanding this, however, the conclusions and findings are still important contributions as, to the author's knowledge, there have been no previous experiments that investigated the effect of interruption management tools



specifically in the ATC domain, and with realistic task relevant interruption sources. As described elsewhere, the findings based on this work are promising and suggest future research directions for integrating awareness tools into the VSCS communication system screens.

### **7.3.2 Novice vs. Expert and Task Design**

As noted earlier in Chapter 5 and 6, participants were novices and did not have direct ATC experience. It is possible that expert air traffic controllers would have different reactions and preferences for the tools.

In addition, as described in Chapter 5, in order to make the task understandable for the novice participants, there were specific modifications done to the task (e.g. all aircraft at a constant altitude), communication protocol and phraseology, as well as the Control and WAIT communication screens. These modifications were made in order to make the interfaces comprehensible and usable for participants with the limited training time available. These changes could also potentially have changed how expert controllers would perceive the different tools. If participants were air traffic controllers or had previous experience in air traffic control such modifications might confuse them since they are not used in a real environment.

Despite the changes, the environment was representative of key characteristics of interruptions in ATC. For example, participants interacted with multiple other human operators, there were domain-relevant tasks, communication activities, and interruptions. Given the early stage, exploratory nature of the work presented in this thesis and the difficulty of recruiting subject-matter experts for widespread participation in experimental trials, it was decided to accept this limitation. As noted above, the findings obtained still provide direction for further work that could hopefully use new web-technologies to make it easier to recruit subject-matter expert participants (Lien et al., 2014).

### **7.3.3 Questionnaire Answer Scales**

There are also limitations that a reader should be aware of with respect to some of the measurement scales used. Some of the questions presented in the experiment analysis (Chapter 6) used non-standard Likert scales; there is a concern that the scales used may unintentionally have created a positive bias in responses due to the uneven balance of response options. The implication of this for the interpretation of the results presented in Chapter 6 is partially offset by two factors. First, the response options for each question were consistent across all experiment conditions and thus any effects would be anticipated to affect the conditions equally. Secondly, in most cases the analysis has focused primarily on differences between the conditions, not the absolute values of an interface on the response scales, and hence a bias effect is not expected to affect the relative preference between conditions. Future work should reconsider the design of questions to remove the potential concern.

### **7.3.4 Design Process and Limits of Participatory Design**

Finally, the design process to develop the WAIT interfaces relied heavily on the Participatory Design process (Chapter 4). While Participatory Design is one way of gaining valuable insights and domain-specific constraints and limitations, it also has a number of disadvantages that could have affected the designs of the WAIT interfaces. For example, participants in Participatory Design (PD) may provide solutions that are strongly influenced by current practices, limiting the ability to develop out-of-the-box and revolutionary products. There is also a concern that PD participants might feel frustrated when their ideas or suggestions are not implemented in the final product (Abrams et al., 2004). Despite this, the PD exercise was valuable in the development of the prototypes. It provided insight into the requirements of developing an interruption management awareness tool, and led to the elimination of

infeasible and impractical suggestions. Future work could consider more radical revisions to existing controller communication interfaces.

## **7.4 Recommendations for Future Work**

The experimental design used in this research can be extended to investigate the important outcomes from participants' feed to the different aspects of the experiment.

### **7.4.1 WAIT Interface**

Developing an interface that provides an urgency level feature for incoming calls and allows both setting the availability manually and automatically depending on user preferences. Furthermore, it is important to explore additional factors that are more precise and accurate in representing controller availability other than the subjective-judgment of availability and the number of aircraft. It would be interesting if the investigation were to be replicated on touch screens, as it was found that using a mouse for some participants delayed the interaction with the WAIT screen, which might have changed their behavior and responses towards the developed features. Furthermore, it is important to study the social impact and consequences of allowing operators to show unavailability status and also make urgent calls, and find suitable measurement and solutions to prevent them from exploiting these features negatively.

### **7.4.2 ATC Radar Screen**

Many participants changed their behavior in dealing with the required aircraft re-routing task when they discovered that performing this task does not affect their score, which was a factor that many were concerned about. For future work, researchers have to consider connecting the study tasks to

goals (e.g. performance score) in order to enforce the consistency of response behavior throughout the study among the participants.

### **7.4.3 Target Participants and Placement**

Observations on the data collected on the utility of the WAIT tool had more credibility by creating a realistic experimental platform, which included the communication sound system, radar screen configuration, and communication protocol among other things. It was also important as to assure that the aircraft scenarios were challenging enough, which was later confirmed by most of the participants in the interview sessions. Further empirical experiments should consider broadening the sample to include not only more participants, but an ATC controller group. Future experiments should also be conducted in real ATC simulation rooms. It is hoped then that this will allow observations on the applicability of the findings in the ATC real-world contexts.

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## Appendix A

### Questionnaire

DEMOGRAPHICS
<ul style="list-style-type: none"><li>• Gender<ul style="list-style-type: none"><li>○ Male</li><li>○ Female</li></ul></li><li>• Years of experience:<ul style="list-style-type: none"><li>○ Trainee</li></ul></li></ul>

- Less than a year
- 1-5 years
- 6-10 years
- More than 10 years

### COMMUNICATION

- What other controllers do you communicate with...
  - when working the “Air” position?
  - when working the “Ground” position?
- What are all the ways you can communicate with other controllers:
  - when working the “Air” position?
  - when working the “Ground” position?
- How frequently do you communicate through these means?

### INTERRUPTION

- Describe situations where you were interrupted by someone not in the tower cab and that interruption was **related** to the task you were performing at that time?
  - Who interrupted you
  - How did they interrupt you
  - What were you doing at the time
  - What sort of information did they need or provide?
  - If this interruption had occurred at a different time, would that have been better?
- Describe situations where you were interrupted by someone not in the tower cab and that interruption was **not related** to the task you were performing at that time?
  - Who interrupted you
  - How did they interrupt you
  - What were you doing at the time
  - What sort of information did they need or provide?
  - If this interruption had occurred at a different time, would that have been better?
- Can you describe for me two situations where you interrupted someone not in the tower cab and that interruption was about the task you were performing at that time?
  - Who did you interrupt?
  - How did they interrupt you?
  - What were you doing at the time?
  - What sort of information did they need or provide?

- If this interruption had occurred at a different time, would that have been better?
- When you are the interruptee (person being interrupted), how frequently does the interruption
  - Create a new task for you (Never, rarely, sometimes, often, always)
  - Provide information for you (Never, rarely, sometimes, often, always)
  - Require you to provide new information. (Never, rarely, sometimes, often, always)
- When you are the interrupter, how frequently does your interruption
  - Create a new task for the other controller (Never, rarely, sometimes, often, always)
  - Provide information for the other controller (Never, rarely, sometimes, often, always)
  - Require the other controller to provide you new information. (Never, rarely, sometimes, often, always)

### **CONTROLLER SITUATIONAL INFORMATION**

One of the ideas that we are exploring to help controllers manage interruptions is a display that automatically shows how busy other controllers are. With respect to the controller that you interrupt most often who is not located in the same tower cab as you,

- What sort of factors makes that controller busy?
- What strategies do you use (if any) to predict the busyness status of that controller?

### **TOOL DESIGN SUGGESTIONS**

- What features do you think would be important in a display showing a controller's willingness to be interrupted?
- An additional idea being explored is a display that shows the urgency of an interruption from another controller. What features do you think would be important in such a display?

## **Appendix B**

### **Recruitment Email**

**Department of Systems Design Engineering  
University of Waterloo**

**PARTICIPANTS NEEDED FOR  
A STUDY TO EXAMINE THE EFFECT OF AN  
INTERRUPTION AWARENESS TOOL ON INTERRUPTION  
MANAGEMENT**

We are looking for volunteers to take part in a research study of improving the management of Controllers' interruptions through the Working Awareness Interruption Tool: WAIT

As a participant in this study, you would be asked to use an air traffic control video-game-like software to monitor the movements of aircraft within a specific sector. You would be asked to communicate with assistants through the WAIT tool and intervene with instructions and interruptions to/from them.

You would also be asked to complete a demographic questionnaire, asked questions about the tool and the tasks, and would be video and audio recorded during the study session.

Your participation would involve one session of three trials lasting approximately 2 hours, scheduled at your convenience. In appreciation for your time and with your agreement, you will receive \$10 at the end of the study session. Also, you will be entered into a draw for a \$100 gift card to a local electronic store.

Note: Participants must have normal or corrected-to-normal vision and must not have any form of color blindness

For more information about this study, or to volunteer for this study, please contact:  
Meshael Alqahtani - Systems Design Engineering  
at  
Email: [m2alqaht@uwaterloo.ca](mailto:m2alqaht@uwaterloo.ca)

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

# **Appendix C**

## **Information Letter**

### **A STUDY TO EXAMINE THE EFFECT OF AN INTERRUPTION AWARENESS TOOL ON INTERRUPTION MANAGEMENT**

You are asked to participate in a research study conducted by Professor Jonathan Histon and Professor Stacey Scott (faculty supervisors) from the Department of System Design Engineering at the University of Waterloo, Meshael Alqahtani (student investigator) from the Department of System Design Engineering at the University of Waterloo, and Nima Hashi (experimenter-assistant). You were selected as a possible participant in this study because the expected population that this research will impact is expected to contain men and women above the age of 18 with an interest in using computers with possible air traffic control or air traffic control-in-training experience. You should read the information below, and ask questions about anything you do not understand, before participating.

Please note that this survey uses Survey Monkey(TM) which is a United States of America company. Consequently, USA authorities under provisions of the Patriot Act may access this survey data. If you prefer not to submit your data through Survey Monkey(TM), please contact the researchers so you can participate using an alternative method (such as through an email or paper-based questionnaire).

#### **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. Additionally, you can decline to answer questions if you wish. The student investigator may withdraw you from this research if circumstances arise which warrant doing so. Only individuals with normal or corrected to normal vision and who are not color blind can participate in this study.

#### **PURPOSE OF THE STUDY**

The overall objective of the research study is to evaluate the effectiveness of the developed tool in facilitating the management of interruptions in collaborative time-sensitive communications. The other goal is to evaluate the effectiveness of the different display conditions for supporting the controllers' interruption situation awareness and then compare the results before and after using

the developed tool. The results will help further our understanding of the displays, which in turn will help us improve our awareness display and may contribute to reducing the impact of interruptions on radar controllers. The evaluation of the effectiveness of these interfaces will be measured through participant performance on interruption situation awareness.

Participants will be asked to take part in three test conditions. The laboratory settings include dealing with visually demanding semi-ATC tasks where participants are expected to send and receive calls while controlling aircraft in their assigned virtual sector on a radar display and communicate through interactive system screens.

## **PROCEDURES**

If you volunteer to participate in this study, we would ask you to do the following things individually:

- You will receive a demographic questionnaire and a consent form. You will be asked to complete them the questionnaire and review the consent form before your scheduled, in-lab session.
- At the beginning of the scheduled in-lab session you will be provided training for using the video game-like software and monitoring the movements of aircraft within a specific sector under your supervision. Also, training will be on the use of the developed communication tool (WAIT). You will receive instruction and have an opportunity to practice intervening with instructions and responding to calls from assistants in the game.
- You will then take part in 3 different task scenarios. Each block for a scenario consists of a specific training session, the execution of several control and communication tasks, and a relevant questionnaire.
- You will be asked to complete an overall questionnaire about the tool and the control and communication tasks
- You will be asked semi-structured questions to further determine your reaction to the software interfaces and the overall session issues
- We will contact you at the end of the data collection period (anticipated to be approximately 3weeks total) via email to inform you of the results of the draw for the gift certificate.

All testing will take place at UW 1303 N rooms, and the approximate time for participation is 2 hrs. The session will be audio and video recorded with your permission.

## **POTENTIAL RISKS AND DISCOMFORTS**

There are no anticipated physical or psychological risks to participation in this study.

## **REMUNERATION FOR PARTICIPATION**



In appreciation of your time commitment, and with your agreement, you will be entered into a draw for \$100 prize (gift certificate) to a local electronic store. Number of entries depends on the session completion status besides the accomplished game score.

- All participants who joined the study session completely or partially will be entered into a draw for a \$100 gift certificate. Also, participants with the five best cumulative scores in the game will be given extra entries into the draw (best score: 5 extra, 2nd best: 4 extra, etc.)
- The draw will take place in the week after the last participant has completed the experiment and will be conducted using an electronic format.
- For those complete the study session, they will receive \$10 at the end of it.

### **CONFIDENTIALITY**

All information obtained will be kept confidential. You will be assigned a participant number which will be used on all related documents to include databases, summaries of results, etc. Only one master list of participants names and numbers will exist that will remain only in the custody of Professor Jonathan Histon and Professor Stacey Scott. Audio and video recordings will be kept securely on the researcher computer. Audio files will be reviewed with headphones preventing any other personnel from overhearing the session recorded. Also, collected data will be preserved in the custody of the professors while it is deemed useful for subsequent research. Access will only be provided to the student who collected the data, or other students within the lab who will conduct follow up work. When deemed no longer useful or relevant, the data will be destroyed.

### **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact the faculty supervisors: Professor Jonathan Histon and he may be contacted by telephone at (519) 888-4567 x37730 or via email at [jhiston@uwaterloo.ca](mailto:jhiston@uwaterloo.ca) or Professor Stacey Scott and she may be contacted by telephone at (519) 888-4567 x32236 or via email at [stacey.scott@uwaterloo.ca](mailto:stacey.scott@uwaterloo.ca). The student principle investigator is Meshael Alqahtani and she may be contacted via email at [m2alqaht@uwaterloo.ca](mailto:m2alqaht@uwaterloo.ca) or cell phone at (519) 722-6526

### **RESEARCH ETHICS CLEARANCE**

This project was also reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Should you have comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or [maureen.nummelin@uwaterloo.ca](mailto:maureen.nummelin@uwaterloo.ca)

# Appendix D

## Consent Form

I have read the information presented in the Information letter about a research study being conducted by Professor Jonathan Histon and Professor Stacey Scott (faculty supervisors) from the Department of System Design Engineering at the University of Waterloo, Meshael Alqahtani (student investigator) from the Department of System Design Engineering at the University of Waterloo, and Nima Hashi (experimenter-assistant).

I am aware that I have the option of allowing the session to be audio and video recorded to ensure an accurate recording of my responses as well as a means of verifying results from other data collected

I am also aware that excerpts from the interview may be included in the thesis and academic proceedings to come from this research, with the understanding that the quotations will be anonymous.

I was informed that I may withdraw my consent at any time by advising the student researcher.

This project has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact this Office at 519-888-4567 ext. 36005.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

### SIGNATURE OF RESEARCH PARTICIPANT

---

Name of Participant

---

Signature of Participant

---

Date

## Appendix E

### Demographic Questionnaire

1. Are you color blind?
  - Yes
  - no
2. Do you have normal or corrected to normal vision?
  - Yes
  - No
3. Please indicate your age below
  - 17 or younger
  - 18-20
  - 21-29
  - 30-39
  - 50-59
  - 40-49
  - 60 or older
4. What is your gender?
  - Male
  - female
5. What is your native language:
  - English
  - Other; please specify: .....
6. If native language is not English, what is your English language proficiency
  - Low
  - Moderate
  - High
7. Occupation:
  - Undergraduate student
  - Graduate student
  - Current or Former Air Traffic Controller
  - Other; please specify: .....
8. If student, what is your major?
  - .....
9. If Current or Former Air Traffic Controller, what is your status:
  - Trainee

- Active
  - Retired
  - Please specify which ATC positions you have experienced with (e.g. radar controller, air controller, data controller, etc.)?
    - .....
  - If you are not a retired controller, what is your current position?
    - .....
  - How many years of ATC experience do you have?
    - .....
10. Do you ever use social media chat communication applications (e.g. Skype, Google Talk, etc.)?
- Yes
  - No
11. If yes, do you ever explicitly indicate your availability/unavailability in any of these chat communication applications?
- Yes
  - No
12. If yes, how often do you explicitly set your availability/unavailability?
- Rarely
  - Sometimes
  - Often
  - Usually
  - Always
  - Please provide an example of one or more typical situation(s) in which you would set your availability:
    - .....
13. Have you ever played any air traffic control simulation game?
- Yes
  - No
14. If yes, please state name of the game/s:
- .....
  - How often do/ did you play it?
    - Once or twice
    - Once or twice a month
    - At least once a week
    - Several times a week
    - Daily

## Appendix F

### Post-Trial Questionnaire

1. How much of a distraction were the INTERRUPTIONS FROM other controllers?
  - No Impact
  - Minor distraction
  - Medium distraction
  - Major distraction
  - Extreme distraction
2. How much of a distraction was it to have TO INTERRUPT OTHER controllers?
  - No Impact
  - Minor distraction
  - Medium distraction
  - Major distraction
  - Extreme distraction
3. Were you able to effectively communicate with the other controllers?
  - Very seldom
  - Hardly ever
  - Some times
  - Most of the time
  - All the time
4. How would you rate your overall performance on the following scale
  - 1 (Very Poor)
  - 2
  - 3
  - 4
  - 5 (Perfect)Comments: .....
5. How important is it to be able to convey the urgency of your outgoing calls to the other controllers?
  - Not at all important
  - Low importance
  - Neutral
  - Moderately important
  - Extremely important
6. How difficult did you find it to communicate the urgency of your outgoing calls?
  - Very difficult
  - Difficult
  - Neutral
  - Easy

- Very Easy
7. How important is it to be able to convey your level of availability to the other controllers?
- Not at all important
  - Low importance
  - Neutral
  - Moderately important
  - Extremely important
8. How difficult did you find it to convey your level of availability to the other controllers?
- Very difficult
  - Difficult
  - Neutral
  - Easy
  - Very Easy
9. If any, what techniques have you used to convey your level of availability to the other controllers other than the provided tool?
- .....
10. How much effort did you apply to the different tasks?
- 1 (Exclusively focused on communicating with pilots)
  - 2
  - 3
  - 4
  - 5 (Exclusively focused on communicating with other controllers)

## Appendix G

### Overall Questionnaire

1. Which representation of the "availability" feature did you find most helpful for managing interruption and why?
  - Manual availability setting
  - Automatic availability setting
  - Reason:.....
2. Which representation of the "availability" feature did you find hardest for managing interruption and why?
  - Manual availability setting
  - Automatic availability setting
  - Reason:.....
3. Did you ever intentionally use your level of availability feature to let other controllers know the status of your availability?
  - Yes
  - No
4. How often did you explicitly think of the urgency level of your outgoing calls?
  - Never
  - Rarely
  - Sometimes
  - Often
  - Always
5. If any, what techniques have you used to predict the urgency of incoming calls?
  - .....
6. In future versions of this systems, how important/not important would it be to show the urgency level of an incoming call?
  - Not at all important
  - Low importance
  - Neutral
  - Moderately important
  - Extremely important

# Appendix H

## Interview

### Experimental Task Questions

1. Did you find the control task challenging?
2. Did you find the control task and communication task difficult to handle at the same time?
3. What are the factors that made it difficult to perform the tasks in the scenario
  - The interfaces were confusing
  - Too many airplanes
  - Instructions confusing
  - I didn't understand the task

### Interface questions:

4. Which interface did you find most helpful for communicating?
  - <sup>2</sup>Basic display interface
  - Manual interface
  - Automated interface
5. Please explain the reason for your answer.
6. Did you ever intentionally use the provided features in the Manual and the Automated condition?
  - If yes, which features did you use?
  - If no, could you explain why you did not use them?
7. In the Manual condition, if you ever intentionally set your availability, how easy or difficult did you find setting your availability?

### Interface questions:

8. Do you have comments or suggestions about the usability of the interfaces?
9. Do you have any other comments or suggestions about the tool features (Availability - Urgency level features) provided in the Manual and Automatic conditions?

---

<sup>2</sup> As shown here in this appendix, the baseline communication interface was presented as the “Basic” interface when the material in this appendix was presented to participants during the experiment. Further reflection while preparing the thesis document suggested naming it as “Control” interface would be more effective when communicating and presenting the results.



# Appendix I

## Training Instruction

### General training:

- Make a call to the East Sector
- Do you remember the three ways of terminating or cancelling calls?
- Terminate the call by calling the pilots
- Receive incoming call from North Sector and don't forget to state your sector
- Terminate the incoming call by using the "End Call" button
- Do you think that DL 5 is facing a problem? How are you going to help DL5 avoid the turbulence
- Can you see a problem facing TH13? Ok Receive the call from South Sector
- Change an aircraft heading in (Center Sector). How would you say that?
- Change an aircraft speed in (Center Sector). How would you say that?
- Help an aircraft to change the speed in (another sector)
- Help an aircraft in (another sector) to avoid a weather condition and back to flight track

### <sup>2</sup>Basic condition training:

- Make a call to the West Sector, and state your sector
- Ask how to inquire about the heading of an aircraft in the Centre Sector. Hint: is it inside or outside your sector?
- Receive the incoming call from South Sector, and state your sector

### Manual condition training

- Set your availability to "Possibly Available"
- Confirm verbally the availability status of the East sector
- Call the (another sector) and convey that your call is "Urgent" , and state your sector (find an accident to talk about)
- How to know acXXX's speed? ( Center sector)

### Automatic condition training

- What is your current Availability status?
- What is the availability status of the North sector?
- Call the XXX sector and convey to her that your call is for a regular matter (i.e. non urgent) like asking about the speed!!
- Find if there is a storm ahead to acXX!! (Center sector)

# Appendix J

## 2 Training Tutorial

### Task Summary

- This experiment puts you in the place of an **air traffic controller**.
- Your job is to safely guide aircraft through your airspace as safely and efficiently as possible.
- You should work on preventing aircraft from colliding with each other or from passing through regions of **thunderstorms** or **turbulence** by communicating with other controllers or pilots
- During your control task, calls occur which will simulate realistic Air Traffic Control communications. Calls may involve control tasks such as **rerouting aircraft** to prevent collisions or may introduce tasks, such as **collecting or providing** information.

HCOM

1

### Experiment Environment

- In the next slide, the two displays that you will interact with during the study sessions will be demonstrated; the following slides explain them in detail.
- Also, the tasks that you are expected to perform will be described.

HCOM

2

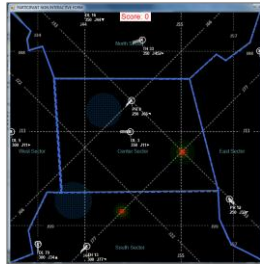
### Experiment Displays: Communication and Radar Displays

#### WAIT Communication Display

*This communication display screen depicts a sample screen. Actual screens may differ slightly.*



#### Radar Display



HCOM

3

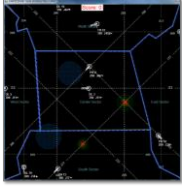
### 1) The Radar Display's main components

HCOM

4

## 1) Radar Display

- The large black portion of the screen is your **radar** display. It visualizes the aircraft movement within a geographical area.
- There are five sectors each controlled by a controller; **you are in charge of "Center Sector"**. The others are the North, South, East, and West sectors.
- Eleven routes** are pre-identified for aircraft to move along named J11, J77, ..., J34.
- Note that the other sectors (North, South, East, and West) appear **partially** in the map, so the aircraft you see are not showing the actual number of aircraft in those sectors



5


## Aircraft Data on the Radar Display

1. In **Figure 1**, each aircraft is attached to a data-tag with several information.

An identifier for the aircraft consisting of an **airline** and a **flight number**. There are 3 airlines only move in the radar map:

- TH 38 = Thunder 38
- PR 8 = Porter 8
- DL 425 = Delta 425

**Figure 1. Aircraft data tag**



An arrow to show the **destination direction** of the aircraft:

- ▲ North, ▼ South,
- ◀ West, ▶ East
- ↖ Northwest
- ↗ Northeast
- ↘ Southeast
- Aircraft PR 8 arrow means it's destination is North East

Aircraft's current **speed** in Knots.


- PR 8 is currently going **250 Knots**

A 2-digit **path-line number** that the aircraft should move along (origin and destination) unless requested to be changed

- PR 8 moves along line **J66**

2. Note that, there might be some aircraft move **freely (don't move along the white dashed lines)**, but it is not your responsibility to control them! It can be recognized by the **3-digit line number** instead of 2 digits as shown in **Figure 2**

**Figure 2. Freely aircraft**





TH 33  
350 J452

TH 33's 3-digit line

6

## Radar Display Score !

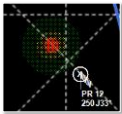
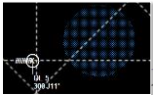
- At the beginning of each session, your performance score is 100%. As negative incidents (aircraft collisions and entering a bad weather areas) occur during the session, you lose points, and the score appears in a negative value.
- Therefore, the closer the score to **"zero"** the better the performance you have.
- Collision**
  - Each moving aircraft will appear as an "x" sign surrounded by a circle all in white – the circle represents half the minimum required distance between aircraft.
  - If the circles of two aircraft overlap, the minimum distance has been violated and a serious error has occurred which will cause the aircraft data color to be red in addition to a score deduction.
  - Consequently, if two aircraft **collided**, you lose **1000 points**

7

## Radar Display Score !

- Storm**
  - You should avoid storms as possible, but if you have to keep an aircraft moving through the green parts of a thunder storm, you won't lose points, but you have to be careful not to go further and enter the yellow or red areas. The points deduction if an aircraft entered a storm area:
    - Green: **no deduction** to the score, but it is still **critical**
    - Yellow: deducts **10 points**
    - Red: deducts **100 point**
- Turbulence**
  - If an aircraft went through a turbulence, the score will be deducted by **one point**.
  - However, you have to prioritize between losing one point and avoiding an aircraft collision or other critical conditions around
  - Note that the turbulences and storms move in time**

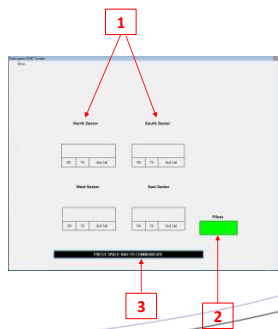



8

## 2) WAIT Communication Display

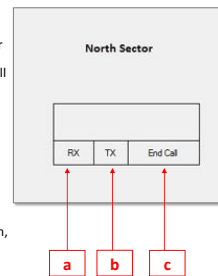
- All the different interfaces you will have share the following features and functionality:

- Four sector channels, labelled with North, South, East, and West, connect you to the controllers of sectors (label 1 in the figure)
- Pilot channel: connects you to the pilots of aircraft within your sector (label 2 in the figure)
- Press-to-talk indicator becomes active by pressing the Spacebar when you want to transmit a call to controllers or pilots (label 3 in the figure)



## Detailed view of a Sector Channel

- Each sector channel labelled with North, South, East, and West connect you to the controllers of that sector
  - "RX" (Receive): when highlighted, indicates a call receiving (label a in the figure)
  - "TX" (Transmit): when highlighted, indicates your voice transmission (label b in the figure)
  - "End call" is a button used to terminate or cancel calls (label c in the figure)
- NOTE: RX and TX are not buttons; You CAN'T click them, yet "End Call" is a button and can be clicked!
- NOTE: Incoming calls have a ringing sound to make you aware of it (Listen to it! 📞)



## Task Goals: Managing Communications

- Incoming or outgoing calls with **CONTROLLERS** are only related to aircraft NOT in your sector area: North, South, East, and West
  - Incoming or outgoing calls with **PILOTS** are only related to aircraft WITHIN your sector area (Center Sector)
- When receiving calls, you should prioritize between responding to the calls and controlling aircraft



## Task Goals: Safety

- Ask pilots or other controllers to change the HEADING or SPEED to maintain safety by avoiding aircraft from colliding or passing through critical weather condition (the steps needed will be explained in the next slides)
- Note that changing the heading or speed is executed gradually, you don't see an instant result, so make sure to request your desired changes ahead of time.
- Also, it is your duty to inform other controllers about any suspected collision or entering into a bad weather area in other sectors
  - Saving your sector OR other sectors from the occurrence of incidents mentioned above saves your radar score from being deducted.

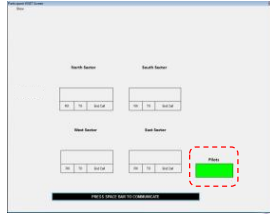
## How to talk to Pilots!

- For aircraft **WITHIN** your sector, you can communicate with their **PILOTS** directly.
- To request a change to an aircraft's heading or speed, communicate that to its pilot by **activating** the "Pilots" channel then **press the Spacebar** and **say out loud** the aircraft airline and flight number and the message you want to transfer.

For example, to ask aircraft **TH 1** to change its speed to 300,

- Make sure that the "Pilots" channel is activated (circled in red)
- Press and **HOLD** the Spacebar on the keyboard
- Say: "THUNDER ONE **reduce/increase** speed to 300"
- RELEASE** the space bar when you finish
- Now you should receive the pilot's acknowledgement

Note: the aircraft have only **three** levels of speed: 250, 300, or 350



## How to Make Calls to other Controllers!

- To request a change to an aircraft outside your designated area, use the channel buttons on the WAIT communication screen to call the responsible controller (sector channel buttons are surrounded by the red dashed shape)

- Suppose that aircraft **PR 12** is closely approaching a storm in the West sector, you have to inform the "West Sector" controller about that by:

- Using the mouse, click "West Sector" channel button on your communication screen (it becomes green)
- On the keyboard, press and HOLD the space bar (this will make "TX" and the push-to-talk long button indicators turn green)
- State your sector then the sector you are calling then say your message.
  - E.g. "Center to West, Porter 12, change heading South East"
- Press "End Call" button when you are done with the call



## How to Receive Incoming calls from other Controllers!

- The process of answering incoming calls is illustrated by the following example,
  - West sector calls (West sector button becomes green and Pilots button becomes gray)
  - You hear a ringing sound
  - Press the spacebar and say "Center Sector" (this will make "TX" and the push-to-talk long button indicators turn green)
  - Release the space bar and listen to the East controller's message

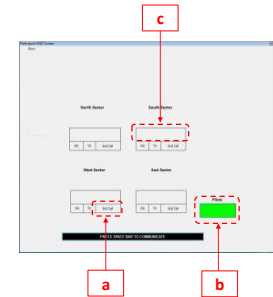


## How to Terminate Calls with Controllers

- There are 3 ways to terminate calls with controllers:

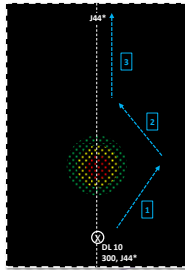
- Pressing "End call" button
- Pressing the "Pilots" button
- Pressing another sector controller button

- Please look here **ONLY** if you were navigated from next sections:
  - [Click here to return back to Automated Interface section](#)



## Adjusting Aircraft Heading in the Radar Display

- If an aircraft's heading was requested to be changed, it is **your responsibility** to communicate with pilots or controllers to ensure it is rerouted back to its pre-set path line (it may take several steps to reroute it back)
- Notes:
  - You want to make sure that aircraft move along these line as possible.
  - However, returning it back to the **exact** line might not be achieved, so few pixels to the right or left, top or bottom is acceptable.

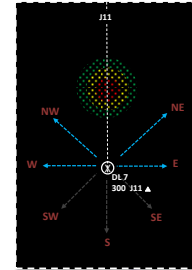


THCOM

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## Radar Display: Adjusting Heading

- Remember that it is your job as an air traffic controller to guide your aircraft to its destination.
- For example
  - If **DL 7** is moving along line **J11**, and there is a storm ahead, you need to maneuver around it while moving in the general direction (**represented by the top-pointing arrow in the aircraft data-tag**) of the aircraft's destination
  - You cannot move in the opposite direction of the aircraft's destination.
  - In this case, you **CANNOT** change the heading of DL 7 to SW, SE, nor S!



THCOM

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## Finally

- **Remember that you don't have to be polite**, people's lives are at stake!!
  - You don't have to precede your speech with Hi, Hello, please,... etc.
- When communicating with pilots or controllers, always **PRESS AND HOLD** the spacebar till the end of your speech.
  - Don't rush and release the spacebar before the end
- **REMEMBER** to release the spacebar while listening to callers talking to you
- If you are done with the call, **END IT** by clicking the "End Call" button or click and activate the pilot button

THCOM

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## BASIC INTERFACE

THCOM

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## WAIT Basic Interface

- This interface allows you to communicate with the other controllers: North, South, East, West controllers.
- Also, it allows you to call the pilots of aircraft in your sector, Center Sector, directly



CHCOM

1

## Basic Interface: Making and Receiving calls

- IF you need to review the way of making or receiving calls to/from controllers or pilots, refer back to slides [14-17](#)
  - There will be a link in [slide 17](#) to take you back to this slide!

CHCOM

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End of Basic  
Interface Training :)

CHCOM

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## MANUAL INTERFACE

CHCOM

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## Manual Interface: Availability And Urgency

- This interface allows you to communicate with the other controllers: North, South, East, West controllers.
- Also, it allows you to call the pilots of aircraft in your sector, Center Sector, directly
- In this trial, the WAIT communication screen will have additional features to help you manage the communications with **other controllers**
- Similar to Facebook or chat application "status", these features will allow you to
  - SET **your availability**, or how important a message from another controller should be for them to call you
  - SEE **other controller's availability**, or how important they think a message should be in order to justify you calling them
- Also, it allows you to SET the **urgency** of a call that you are making to them
- Specific details of how these features are implemented are described next

## WAIT Communication Display: Manual Interface

- The **first** new feature in **Manual** interface gives you the ability to set up your **availability level manually** based on your personal judgement of your availability (**this feature is surrounded by the top-right red shape in the figure**)
- To change your availability, click one of the three buttons of the availability box (**My availability**)
  - Therefore, other controllers will be aware of your availability prior to calling you.
  - Your availability would effect other controllers' decisions of making calls to you
- Also, you will be able to view other controllers' availability when you call them (**surrounded by the bottom-right red shape in the figure**)



## WAIT Communication Display: Manual Interface Features

• Therefore, the manual interface provides you with the ability...

1. **to set-up** your availability status as the following:
  - **Red**: (figure 1)
    - Not Available – only call me with **EXTREMELY IMPORTANT** messages; I'm very busy
  - **Yellow**:
    - Possibly Available – call me only with **IMPORTANT** messages; I'm somewhat busy
  - **Green**(default):
    - Available – call me about **anything**; I'm not that busy
2. **to receive** calls from other sectors controllers the same way as in the other WAIT interfaces (figure 2)



Figure 1: Performer's availability



Figure 2: A call from the West sector

## Manual Interface Features

3. **to view** other controller's level of availability
  - Once you click the button to call another controller, his/her status will appear on the right side of the screen under the label "Controller's Availability".
  - In the figure, the "South sector" controller's level of availability shows a **Red light** which means he/she is **available ONLY FOR EXTREMELY** important messages.
  - Note, even if any controller has a red status, you still can call them if you think it is a serious matter.





## Manual Interface Features: Specifying Urgency Level of a Call

4. **to specify** the urgency level of your outgoing calls to other controllers, and this is the **second provided feature** in this interface

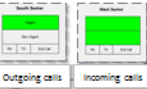
– Click one of the controller's channel button divisions that resembles the level of your call

- Top: **Urgent**
- Bottom: **Non Urgent** (regular matters)

– In the top figure, your outgoing call has a high urgency level

- Also, note that, unlike outgoing calls, incoming calls **do not** show the urgency level of the call; all button subdivisions will be **highlighted**.

– Think of it as your sector provides its controllers (you) with a sophisticated communication system, but this feature is not provided in the devices of other sectors around you



## WAIT score

- Finally, the Manual interface calculates a **score** that depends on the time you set manually for each availability level.
- Setting your availability as **RED**, makes you gain **the least points**.
  - Red: 10 points/second
  - Yellow: 20 points/second
  - Green: 30 points/second
- At the end of the study session, the WAIT score and the Radar score will be **summed up**
- **Remember that** participants with five best cumulative scores will be given extra entries into the draw!!



## End of Manual Interface Training :)

## AUTOMATED INTERFACE

## Automated Interface: Availability And Urgency

- This interface allows you to communicate with the other controllers: North, South, East, West controllers.
- Also, it allows you to call the pilots of aircraft in your sector, Center Sector, directly
- In this trial, the WAIT communication screen will have additional features to help you manage the communications with **other controllers**
- Similar to Facebook or chat application "status", these features will allow you to
  - SET **your availability**, or how important a message from another controller should be for them to call you
  - SEE **other controller's availability**, or how important they think a message should be in order to justify you calling them
- Also, it allows you to SET the **urgency** of a call that you are making to them
- Specific details of how these features are implemented are described next

## WAIT Communication Display: Automated Interface

- The **first** new feature in the **Automated** interface allows **your availability** to be set-up **automatically** based on the number of aircraft you are controlling within your sector and (this feature is surrounded by the top-right red shape in the figure)
- So, your availability is going to be set up automatically, and you don't have to do any thing for that
  - Therefore, other controllers will be **aware** of your availability prior to calling you.
  - Your availability **would affect** the other controllers' **decision** of making calls to you
- Also, you will be able to view other controllers' availability when you call them (surrounded by the bottom-right red shape in the figure)



## WAIT Communication Display: Automated Interface

- The automated interface availability provides you with the ability...
- to convey** your availability status as the following:
    - Red:** you are controlling > 4 aircraft
      - You are **not available**
      - Your availability means "ONLY call me with **EXTREMELY IMPORTANT** messages; I'm very busy"
    - Yellow:** you are controlling 3-4 aircraft (figure 1)
      - You are **possibly available**
      - Your availability means "call me only with **IMPORTANT** messages; I'm somewhat busy"
    - Green:** you are controlling 0-2 aircraft
      - You are **available**
      - Your availability means "call me about **ANYTHING**; I'm not that busy"

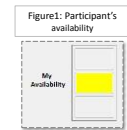


Figure 1: Participant's availability

The automatic changes of the availability levels has a special sound (Listen to it! 📢)

## Making calls in the Automated Interface

- to receive** calls from other sector's controllers as similar to all variants of WAIT interfaces (figure 2)
- to view** other controller's level of availability
  - Once you click the button to call another controller, his/her status **will appear** on the right side of the screen under the label "Controller's Availability".
  - In Figure 3, the "South sector" controller's level of availability shows a **Red light** which means he/she is **available ONLY FOR EXTREMELY** important messages.
  - Note, even if any controller has a red status, you **still can** call them if you think it is a serious matter.



Figure 2: A call from the West sector



Figure 3: A call to the South sector

## Specifying Urgency Level of a Call

4. **to specify** the urgency level of your outgoing calls to other controllers, and this is the **second provided feature** in this interface

– Click one of the controller's channel button divisions that resembles the level of your call

- Top: **Urgent** (see Figure1)
- Bottom: **Non Urgent** (regular matters)

– In the top figure, your outgoing call has a high urgency level

- Also, note that, unlike outgoing calls, incoming calls **do not** show the urgency level of the call; all button subdivisions **will be highlighted**.

– Think of it as your sector provides its controllers (you) with a sophisticated communication system, but this feature is not provided in the devices of other sectors around you



Figure 1: An urgent  
Outgoing call to the South  
sector



## Automated Interface: Making and Receiving calls

- IF you need to review the way of making or receiving calls to/from controllers or pilots, refer back to slides [14-17](#)
  - **There will be a link in slide 17 to take you back to this slide!**

## Appendix K

### “R” Code Used to Present Comparisons across Conditions

```
library(lattice)
library(RColorBrewer)
myColours <- brewer.pal(6, "Blues")
wordwrap<-function(x,len) paste(strwrap(x,width=len),collapse="\n")

comma_formatter <- function (lim, logsc = FALSE, at = NULL, ...)
{
  ans <- yscale.components.default(lim = lim, logsc = logsc, at = at, ...)
  xx = as.numeric(ans$left$labels$labels)
  ans$left$labels$labels <- sprintf("%s%%",xx)
  ans$left$labels$cex <- c(2,2,2,2,2,2)
  ans$left$tck <-c(0)
  # ans$left$labels <- TRUE
  ans
}

if (1)
{
  df=read.table("clipboard", sep = "\t", header = TRUE)
  #df$RatingLevel <-sub(" ", "\n",df$RatingLevel)
  #df$Condition<- factor( df$Condition, levels=c("Control","Manual","Automated"))
  df$Condition<- factor( df$Condition, levels=c("Automated","Manual","Control"))
  if (0)
  {
    df$RatingLevel<- factor( df$RatingLevel, levels=rev(df$RatingLevel[c(1,2,3,4,5)]), ordered = TRUE)
  }
  else
  {
    df$RatingLevel<- factor( df$RatingLevel, levels=df$RatingLevel[c(1,2,3,4,5)], ordered = TRUE)
  }
}

my.settings <- list(
  superpose.polygon=list(col=c(
rgb(77,175,75,maxColorValue=255),rgb(228/255,26/255,28/255),rgb(55/255,126/255,184/255)),
border="transparent"),
  strip.background=list(col="grey20"),
  strip.border=list(col="black"),

  layout.widths.left <-4,
  layout.widths.left.padding <- 14)
```

```

barchart(100*df$Frequency~RatingLevel | Condition,
  groups=Condition,
  data=df,
  layout = c(1,3,1),
  stack = TRUE,
  yscale.components =comma_formatter,
  scales = list(
    x=list(
      font = 2,
      cex = 1.9,
      alternating = FALSE
    ),
    y=list(
      font = 2,
      cex=2,

      alternating = 2)
  ),
  strip = FALSE,
  strip.left = strip.custom(style = 1, horizontal = FALSE),
  between = list(y=0.5),
  par.settings = my.settings,
  par.strip.text=list(
    col="white", font=2,cex=2.5),
  ylab = list(
    label="Condition",
    cex=3,
    font = 2

  ),
  ylab.right = list(
    label="% of Participants",
    cex=3,
    font = 2

  ),
  # auto.key=list(
  #   space="top",
  #   columns=3,

  #   cex.title=1.5,
  #   reverse.rows = TRUE
  # )
)

```