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Human-Centred Design for Next Generation of Air Traffic Management systems

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Human-Centred Design for Next Generation of Air Traffic Management systems

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ABSTRACT

Designing and deploying air traffic management systems requires an understanding of cognitive ergonomics, system integration, and human-computer interactions. The aim of this research is to develop an effective Human-centred design for Air Navigation Services Providers to permit more effective air traffic controller training and regulations. Therefore, this research consists of both evaluating human-computer interactions on COOPANS Air Traffic Management system and multiple remote tower operations. The COOPANS Alliance is an international cooperation among the air navigation service providers of Austria, Croatia, Denmark, Ireland, Portugal and Sweden with Thales as the industry supplier. The findings of this project indicate that the context-specified design of semantic alerts could improve ATCO's situational awareness and significantly reduce response time when responding to aircraft conflict resolution alerts. Civil Aviation Authorities, Air Navigation Service Providers and Air Traffic Management System Providers could all benefit from the findings of this research with a view to ensuring that Air Traffic Controllers are provided with the optimal context-specified alerting schemes to increase their situational awareness during both training and operations. The EU Single European Sky initiative was introduced to restructure European airspace and propose innovative measures for air traffic management to achieve the objectives of enhanced cost-efficiency and improved airspace design and airport capacity whilst simultaneously improving safety performance. There is potential to save approximately €2.21 million Euro per annum per installation of remote tower versus traditional control towers. However, ATCO's visual attention and monitoring performance can be affected by how information is presented, the complexity of the information presented, and the operating environment in the remote tower centre. To achieve resource-efficient and sustainable air navigation services, there is a need to improve the design of human-computer interactions in multiple remote tower technology deployment. These must align with high technology-readiness levels, operators' practices, industrial developments, and the certification processes of regulators. From a regulatory perspective the results of this project may contribute to European Aviation Safety Agency rulemaking activity for future Air Traffic Management Systems. Overall, the results of this research are in line with the requirements of Single European Sky and facilitate the harmonisation of European ATM systems.

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GLOSSARY

AAIB	Air Accidents Investigation Branch
AFIS	Aerodrome Flight Information Services
AMC	Air Movement Control
ANS	Air Navigation Services
ANSP	Air Navigation Service Providers
APW	Area Proximity Warning
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATS	Air Traffic Services
CAA	Civil Aviation Administration
CWP	Controller's Working Position
EASA	European Aviation Safety Agency
EFS	Electric Flight Strips
FAA	Federal Aviation Administration
HCI	Human-Computer Interaction
HEI	Human Error Identification
HET	Human Error Template
HTA	Hierarchical Task Analysis
IAA	Irish Aviation Authority
ICAO	International Civil Aviation Organisations
IDP	Information Data Processing
LSD	Large Scale Demonstration
MASO	Multiple Airport Simultaneous Operations
MRTO	Multiple Remote Tower Operations
MSAW	Minimum Safe Altitude Warning
OTW	Out of Windows
PTZ	Pan-Tilt-Zoom
RDP	Radar Data Processing

RTC	Remote Tower Centre
RTO	Remote Tower Operations
SA	Situation Awareness
SESAR	Single European Sky ATM Research Programs
SMC	Surface Movement Control
STCA	Short Term Conflict Alert
VCS	Voice Communication System

CHAPTER I

Introduction

1.1 Background

Designing and deploying air traffic management systems for human-computer interactions requires an understanding of the principles of cognitive system engineering, allocation of functions and team adaptation between human operators and automations. A holistic approach to the design of air traffic management systems is required so that the human operator can maximise their effectiveness within these complex systems especially during rapidly changing situations. Future human-centred design of multiple remote tower operations should be based on a strategic, collaborative and automated concept of operations, as high performance in conflict detection and resolution has the potential to increase both airspace efficiency and the safety of aviation operations. Acknowledging the continued growth of aviation in Europe and the respective frameworks designed by technology programs such as SESAR, Vision 2020 or NextGen, there is a need to develop Human-Centred Design for ATM systems. Therefore, this thesis has explored alerting design on the COOPANS ATM system and certification processes for multiple remote tower operations (MRTO) and generated four published papers and one additional paper awaiting publication, as follows,

(1) Chapter Two is based on the published paper: Kearney, P., Li, W-C. & Lin, J. (2016). The Impact of Alerting Design on Air Traffic Controllers' Response to Conflict Detection and Resolution. International Journal of Industrial Ergonomics, 56, 51-58.

(2) Chapter Three is based on the published paper: Kearney, P., Li, W-C., Yu, C-S. & Braithwaite, G. (2018). Application of Semantic Design to Support Air Traffic Controllers' Conflict Detection and Resolution to Short Term Conflict Alert. *Ergonomics*. DOI:10.1080/00140139.2018.1493151

(3) Chapter Four is based on the published paper: Li, W-C., Kearney, P., Braithwaite, G. & Lin, J. (2018). How much is too much? Visual Scan Patterns of Single Air Traffic Controller Performing Multiple Remote Tower Operations. *International Journal of Industrial Ergonomics, 67,* 136-144.

(4) Chapter Five is based on the submitted paper: Kearney, P., Li, W-C. & Braithwaite, G. (under review). Applying Human Error Identification Method to Evaluate Single Air Traffic Controller Conducting Multiple Remote Tower Operations. *International Journal of Human Factors and Ergonomics in Manufacturing and Service Industries*.

(5) Chapter Six is based on the published paper: Kearney, P. & Li, W-C. (2018). Multiple Remote Tower for Single European Sky: The Evolution from Initial Operational Concept to Regulatory Approved Implementation. *Transportation Research Part-A, 116,* 15-30.

1.2 Human-Centred Design for ATM System Integrations

Anticipating the future growth of air traffic services, there are demanding requirements on air navigation service providers to apply advanced technology to support enhanced safety, capacity and efficiency. The design of the semantic alert significantly decreased ATCO's response time by not only presenting salient signals (level-1 of SA), but also providing

ATCO’s with knowledge of the nature of the situation to be resolved (level-2 of SA). Therefore, ATCO’s have more time to project the evolving flow of aircraft in the near future (projection of future status, level-3 of SA), and develop more effective resolutions to critical events, permitting a more rapid return to ensuring the rest of the aircraft under his/her control continue to be managed in a safe and efficient way (Endsley, 1997).

Deploying these new technologies, such as remote tower technology also requires development of procedures and processes to acquire regulatory acceptance of the use of these technologies. Multiple remote tower operations involves providing aerodrome control service for several airports from a remotely located control centre without a physical presence by air traffic controllers at the airports under control, supported by innovative technology. Remote Tower technology is applicable to larger international airports as well, in some cases potentially as the primary tower and in others as a fully functioning contingency or backup system. The innovative concept of multiple tower operations will require changed procedures and standards from those prescribed in the International Civil Aviation Organisations Doc 4444 (Air Traffic Management) and EUROCONTROL’s Manual for Aerodrome Flight Information Services (Eurocontrol, 2015). Differences between ATC provision from RTC compared to traditional physical towers requires careful consideration and in-depth assessment to validate the safety level of human performance for multiple remote tower operations, as this method involves increased cognitive demands for a single ATCO performing several ATCOs’ tasks (Hollan, Hutchins, & Kirsh, 2000; Kearney, Li, Braithwaite, & Lin, 2018).

In the working environment of a physical tower, the constantly shifting attention between outside views and equipment displays generates workload and accumulates head-down time problem solving (Pinska, 2006). Both workload and head-down issues can be resolved by augmented vision design of OTW by superimposing traffic information and weather conditions on the airfield (Fürstenau & Schmidt, 2016; Schmidt, Rudolph, & Fürstenau, 2016). Augmented vision, by digital reconstruction of the far view, by high-resolution videopanorama PTZ will be a critical interface for human-computer interaction of MRTO. Suitably designed human-centered ATM systems can significantly improve controllers' situation awareness and reduce their cognitive workload (Laois & Giannacourou, 1995; Tobaruela et al., 2014), providing increased capability to perform complex tasks (Wickens & Hollands, 2000). However, inappropriately designed automation can present many disadvantages and create potential system risks leading to incidents /accident, including loss of SA, and substituting the human operators outside of the system control loop (Durso et al., 1998).

The remote tower module consists of a camera array pan tilt zoom (PTZ) cameras at Cork and Shannon airports controlled from a Remote Tower Centre (RTC) at Dublin ATS unit. Saab is the supplier of both the remote tower equipment and the EFS system. Cork and Shannon airports have the SAAB Remote Tower Pod containing 14 high definition cameras and 14 infra-red cameras providing aircraft/vehicle observation in low visibility weather conditions with 360-degree field of view. This augmented visualisation design is to enhance ATCO's situation awareness and followed information-processing model (Endsley, 1995). ATCO's visual behaviours provided an opportunity to investigate the relationship between situation awareness and task performance, as ATCO's task performance is mainly monitoring aircrafts and vehicles activities on interface displays such as OTW, PTZ, EDP and EFS. Eye scan pattern analysis is one of the most powerful methods for assessing human beings' cognitive processes (Ahlstrom & Friedman-Berg, 2006). ATCOs have to distribute their attention to detect potential conflicts among aircraft in the air and airfield in order to maintain situation awareness. Efficient monitoring and an augmented visual channel is foreseen as the most promising way to increase the capacity and safety of air traffic services (Beier & Gemperlein, 2004).

1.3 New Technology Induced New HCI Challenges

Air Traffic growth in recent years has highlighted deficiencies in infrastructure and airspace capacity resulting in increasing delays to aircraft and passengers in Europe. In order to address these concerns, the Single European Sky initiative has been set up with the following objectives - improve safety, reduce airspace user costs and minimise environmental impact whilst at the same time increasing efficiency and capacity in order to meet the requirements of growing air traffic numbers (Eurocontrol, 2015). ATCOs' visual search whether on a radar display or at aerodrome control tower is critical for maintaining situation awareness, and ATCOs' visual attention can be heavily influenced by the surrounding environment and equipment interface design of the Controller Working Position (CWP). In order to achieve an understanding of the effects of different design on cognitive function, it is necessary to apply a holistic approach which includes a comprehensive assessment of human performance on MRTO (Lafond et al., 2009). The HCI design of the CWP including Electric Flight Strips (EFS), Radar Data Processing (RDP), Voice Communication System (VCS) and Out of Window screens (OTW) impacts on an ATCO's cognitive processes in terms of attention distribution, situation awareness and decision-making.

There are two aerodrome ATCOs in the traditional towers at Shannon and Cork airports including an air movement's controller and a surface movements controller. The multiple remote tower operation offers the opportunity of providing aerodrome control services for two or more small airports from a RTC without direct presence at the airports by a single ATCO. The aim of multiple remote tower operations is to deliver benefits in line with

SESAR's high-level objectives, to enhance ATCO's situation awareness, to improve productivity, to enhance system contingency all at the same time as maintaining at least the same level of safety from traditional towers (Eurocontrol, 2014). It is based on the assumption that new technology will better facilitate ATCO's situation awareness, improve the quality of decision-making, so that therefore, one controller would be capable of performing all the tasks of monitoring, supervising, and communicating involved in controlling two different airports which in a traditional system would be performed by four ATCOs. Air traffic controllers must make rapid judgments of the situation presented by the ATM system, and then take appropriate decisions and actions to ensure aviation safety and maximise airspace and runway efficiency. Managing complicated ATM systems to keep safe separation between aircraft is not only an issue of technical skill performance but also of real-time decision-making involving situation awareness and risk management within a time-limited environment (Ltifi, Kolski, & Ayed, 2015). In order to predict aircraft position in the near future, the aircrafts current disposition must be used as a basis for a cognitive projection model, and this implies that longer and more frequent periods of attention must be devoted to processing all relevant information. Although good performance was maintained, greater workload was experienced and measured (Marchitto et al., 2016).

1.4 Enhancing Human Performance Also Increasing Task-Loads

Air traffic activities are constantly evolving as a result of different aircraft types with varying performance characteristics, traffic volumes and weather conditions. Therefore, ATCO's have to deal with more and more information that could cause a significant increase in their workload. Appropriate interface design in ATM systems can discharge ATCO cognitive loads and enhance SA by facilitating a better match between task demands and cognitive resources (Kaber, Perry, Segall, Mcclernon, & Iii, 2006). The effective coordination of the human-computer interaction is crucial for the successful implementation of innovative systems in the MRTO environment. Interface design must apply holistic approaches to facilitate distributed cognition coordination in rapidly changing situations (Langan-Fox, Canty, & Sankey, 2009), as high performance in conflict detection and resolution has the potential to increase aviation safety and enhance airspace efficiency (Schuster & Ochieng, 2014). ATCOs' task performance and perceived workload might increase due to interactions with innovative technologies requiring operators to process more information and monitor more targets on the interface displays. In the dynamic aviation environment, effective human performance is highly dependent on situation awareness which is the precursor for all tasks of decision-making.

The goal for an ATCO is to find ways to safely expedite an orderly flow of air traffic. The workload of the controller is a function of the flow of air traffic, at times leading to cognitive overload and underload. These cognitive workloads increase the risk for inattentional tunnelling, cognitive lockup, and the out-of-the-loop syndrome (Endsley, 1995). One of the most commonly used measures of operator's perceived workload is NASA Task Load Index (Hart & Staveland, 1988). This cognitive assessment tool is a subjective assessment method that uses self-reported rating scores at a given moment in time. The advantage of these self-reported workload ratings is the ease of application. Workload can negatively affect ATCOs' performance and increase the errors in operations (Athènes et al., 2002). Workload is the load imposed on the limited information processing resources of the unaided (without assistance of automation) human operator and is described as the "baseline" or "manual" condition. This load can be imposed from two qualitatively distinct sources, the single task difficulty of the task that might otherwise be automated, and the multitask load in which the baseline task is performed. Task management is directly related to mental workload, as the competing demands of tasks for attention exceed the operator's limited resources, and better multitask performance results from rapid switching between tasks (Wickens, 1992).

The development of new remote tower technology is designed to reduce ATCO's workload through augmented vision presented on OTW, RDP and EFS. However, sometimes the complexity of advanced technology may create other human-computer interaction issues by providing too much information that may increase rather than decrease human operator's workload (Wiener, 1988). The operational requirements of task performance on multiple remote tower operations involved more moving targets and more monitoring tasks than in a traditional tower operation, ATCO's must work very hard to maintain safe separations, therefore an ATCO may suffer from fatigue and may experience discouragement, irritation, stress and annoyance.(Cao et al., 2009). These factors may explain the significant higher mental demand, temporal demand, effort and frustration scores noted on the NASA TLX assessment of MRTO compared to traditional tower operations. ATCOs have to maintain the same level of performance to ensure the safety of operations at the cost of high cognitive loads instead of physical demand.

Previous research demonstrated that low workload had a negative influence on performance as it can aggravate boredom, and high workload can result in poor performance due to stress or overload (Eggemeier, 1988); however, high workload might provoke a strategy shift so that the operators perform well (Moehlenbrink, Papenfuss, & Jakobi, 2012). High density traffic and dynamic aircraft manoeuvres in terminal airspace can increase ATCO's perceived workload. This research finds that NASA-TLX may reflect different components of workload including 6 dimensions and it may not co-vary with measures of all aspects of performance (Hart, 2006). Workload can impact ATCOs' performance and increase errors in operations. Information presentation on the remote tower module and information interpreted by the ATCO are crucial elements in assuring aviation safety. Current OTW and EFS on RTM demonstrate that augmented visualisation and information presentation can facilitate ATCOs' cognitive processes and reduce monitoring task-loads. One ATCO is able to perform the tasks originally designed to be completed by four ATCOs with the same level of safety, however it doesn't mean that the ATCO's perceived workload remains the same. This leads to a requirement to balance cost-efficiency and safety of operations from the human factors perspective. Air Navigation Service Providers must be prepared to conduct their own human factors analysis of new systems and procedures prior to deployment to ensure these both compliment overall system performance and safety for the environment in which they operate.

1.5 Aims and Research Objectives

Air Traffic growth in Europe in recent years has highlighted deficiencies in infrastructure and airspace capacities resulting in increasing delays to aircraft and passengers. To address these concerns, the Single European Sky initiative was established with the following aims - improve safety, reduce airspace user costs and minimise environmental impact whilst at the same time increase efficiency and capacity in order to meet the requirements of growing air traffic numbers. These are laudable aims but have inherent conflicts for example between reducing costs and increasing safety. This generates a risk that Air Navigation Service Provider's in response to reducing costs deploy new technologies without sufficient analysis of the implications of these new technologies on the personnel who must operate them, leading to unintended consequences and potential safety risks. The objectives of this research are (1) to develop effective Human-Computer Interaction (HCI) of alerting design on COOPANS; (2) to measure ATCOs' perceived workload and visual behaviours to explore Human-Centred design of alerts; (3) to explore human limitations on monitoring tasks for multiple remote tower operations based on air movements and surface movements; (4) to assess human performance on multiple remote tower operations; and (5) to develop certification processes for multiple remote tower operations to be applied by regulators. The focus will be on human performance and the associated information and support tools used by an Air Traffic Control Officer (ATCO) ensuring that these tools are used safely and efficiently to control aircraft both remotely and for multiple airports.

CHAPTER II

The Impact of Alerting Design on Air Traffic Controllers' Response to Conflict Detection and Resolution

2.1 Introduction

The COOPANS Air Traffic Management (ATM) System provides three kinds of alerts which are designed to alert controllers to three distinct critical risks, Short Term Conflict Alert (STCA), Minimum Safe Altitude Warning (MSAW), and Area Proximity Warning (APW). Activation of any of these three alerts by acoustic design indicates a potential conflict of aircraft, conflict between aircraft and prohibited airspace and conflict between aircraft and terrain, therefore the air traffic controller is expected to respond and resolve the potential conflict as fast as possible to ensure the safety of the aircraft. The COOPANS system is deployed in five countries within Europe, Ireland, Denmark, Sweden, Austria and Croatia, and the air traffic controllers (ATCO) within these five countries all operate a harmonised system which provides three critical alerts using the same audio alerting schema. Furthermore, the COOPANS system is seen as a major step in achieving the European Union aspiration of harmonised ATM systems across Europe in support of Single European Sky (Eurocontrol, 2015).

The activation of the STCA alert on the COOPANS system provides a 90 second warning, that unless appropriate action is taken by air traffic controllers to resolve the conflict, significant risk of collision between aircrafts exists. This introduces time pressure on the ATCO's to identify the nature of the alerts and respond with air traffic control instructions which resolve the conflict situation (Eurocontrol, 2014). However, previous safety recommendations from aircraft accidents linked to controlled flight into terrain and aircraft collision revealed that most of these accidents occurred in circumstances where MSAW and STCA were available to ATCO's. All of these accidents demonstrated that alerting system configurations provided alerts of the impending situation, but ATCO's failed to provide timely safety advice to flight crew (NTSB, 2006). The report also indicated that ATM systems were not adequately designed so as to provide ATCO's with effective situation awareness (SA) to make timely decisions. Air traffic controllers must make a rapid judgment of the situation that is being signalled by the automatic alerts provided by an ATM system, and then take the appropriate decision to ensure aviation safety. Interestingly research spanning from 1977 to 2008 has demonstrated that decision errors in aviation may be contributing to up to 60% of all aviation accidents (Jensen & Benel, 1977; Buch & Diehl, 1984; Diehl, 1991; Li & Harris, 2008). Furthermore, recent accident investigations found that poor air traffic control might impact on aviation safety (Daramola, 2014). The current ATM system is reactive and inefficiencies result in delays with associated negative impacts on economy and safety. Therefore, there is an urgent need to develop novel and strategic methods for ATM, making use of current and future technologies to enable better planning and thereby increase capacity and efficiency, without jeopardising safety (Schuster & Ochieng, 2014).

2.1.1 Alerting designs Impacting ATCO's' situation awareness

Current COOPANS system has a potential design issue which is an alert activation for STCA, MSAW or APW might be misinterpreted as the acoustic signal for all three alerts is the same (Beep-Beep-Beep-Beep). This has the potential to induce an ATCO's into misjudging the type of critical alert being presented and in the worst circumstances the ATCO's response may be to simply silence the acoustic alert, not solve the separation risk for example, thereby weakening system safety. Design of salient alerts for ATM systems might be excellent at capturing ATCO's attention and increasing SA. However, this salient alert might immediately divert operator's attentional resources away from the ongoing task, incurring other issues such as startle and primary task error by distraction (Imbert et al., 2014). Suitably human-centered designs of automated alerts in ATC can have significant effects on controllers' performance and reduced cognitive workload (Laois & Giannacourou, 1995; Tobaruela et al, 2014), with increased capability to perform complex task management (Wickens and Hollands, 2000). However, inappropriate design of automation can present many disadvantages and create potential risk leading to accident/incidents, including loss of SA, and substituting the human operators outside system control loop (Durso et al, 1998; Endsley, 1995).

Intensity of audio alert designs can be modified based on task demands and working environment in order to optimise ATCO's performance. In addition to audio intensity level, the semantic content of an auditory alert that conveys the appropriate hazard level is the central component to increasing operators' SA (Edworthy & Hellier, 2006). Appropriate design of automation in ATM systems can assist in moderating ATCO workload and improving SA by facilitating a better match between task demand and cognitive resource (Kaber et al., 2006). The effective coordination of the human-automation team is crucial to the successful implementation of ATM systems in the future. Designing and managing human-automation teams require an understanding of principles of cognitive system engineering, allocation of function and team adaptation. It is a holistic approach by distributed cognition coordination to rapidly changing situations (Langan-Fox, Canty, & Sankey, 2009). Future human-centered design of ATM system shall be based on a strategic, collaborative and automated concept of operations, as high performance in conflict detection and resolution has the potential to increase both airspace efficiency and the safety of aviation (Schuster & Ochieng, 2014). Based on the above literature review, current research will investigate ATCO's SA between the current acoustic alert and new semantic alert developed by the authors. Therefore, the first null hypothesis of current research is

"H_0: designs of alert has no significant effect on ATCO's SA"; and the alternative hypothesis is "H_1: design of semantic alert can improve ATCO's SA compared with acoustic alert".

2.1.2 Working experience and information processing

Task performance between novices and experts are different, experts are better at predicting future states than novices (Roth and Woods, 1988; Wickens, 1992). Experts' mental representations are more organised and conceptually richer than novices; as a consequence, expert's decision-making relies on a deep understanding of situations, whereas novices are based on rigid rules (Hoffman, Trafton & Roebber, 2007). In circumstances of time-limited situations, such as ATC, the faster the mental processing of the task the better the performance and the faster the processing is completed, the more time is available for subsequent tasks (Salthouse, 1992). Experienced controllers showed a higher proportion of relative gaze duration and relative fixation duration on relevant areas within the orientation phase than in the other phases. The reason could be that experts spend more time than novices in forming a conceptual understanding of the problem in order to build up a richer and more organised mental representation of the situation (Bruder et al., 2014).

Research in aviation demonstrated that experienced pilots performed in a superior manner compared with less experienced pilots in a study at recognising deteriorating weather conditions (Wiegmann, Goh & O'Hare, 2002). Furthermore, experts and novices differ in response to dynamic situations; experts were considerably more context-dependent in evaluating situations than novices, allowing them to evaluate situations more holistically than novices (Strauch, 2004). The increased experience in the environment should lead to the formation of high level structure such as schemata or mental models, which can be used to organise the complexity and multiplicity of objects in the environment; it can be observed by experienced controllers generating a cognitive picture more easily and faster than novice controllers (Endsely & Bolstad, 1994). There is a need to investigate air traffic controller response time between novices and experts, therefore, the second null hypothesis of current research is “H_0: working experience has no significant effect on ATCO’s response time”; and the alternative hypothesis is “H_1: experienced ATCO’s response time quicker than novice’s response time”.

2.1.3 Alerts and ATCO’s conflict resolution

Monitoring aircraft information is an important part of the ATCO’s task. Previous research identified a number of safety concerns with ATM systems, such as lack of uniqueness of alarms, multiple false alarms, alarms being counter intuitive and alarms being annoying and increasing ATCO’s workload (Ahlstrom, 2003; Newman & Allendofer, 2000). In the ATC domain, the activation of a safety alert means that the air traffic controllers must resolve a critical situation, often while under time pressure. Auditory alerts can attract the operator’s attention regardless of where visual attention is directed, if presented at an audio level to sufficiently overcome background noise. However, the effect of auditory alerts can be diminished if the presentation of an acoustic alert is too high which can lead to controllers being startled. Verbal warnings tailored to specific hazard situations may improve hazard-matching capabilities without substantial trade-off in perceived annoyance (Baldwin, 2011). The main purpose of ATC is to optimise the flow of traffic and to separate aircraft to prevent collisions both in the air and on the ground; therefore, an examination of all possibilities to enhance ATCO’s monitoring performance using advanced technology is required (Alonso et al., 2013).

A key objective of ATM system design should be to enable the controller to integrate existing information with the evolving traffic state within the airspace under control. The need to evaluate rapid change in a timely fashion is critical, as inappropriate clearances could place aircraft on conflicting paths thereby disrupting the entire traffic management scheme (Wickens, Miller & Tham, 1996). Problem-solving studies show fundamental differences between novices and experts in how problems are interpreted, what strategies are devised, what information is used, memory for critical information, and speed and accuracy of problem solving. Experts can see underlying causes and have more complex models of problem solving than novices (Larkin et al, 1980). Therefore, current research is aiming to conduct an investigation into the current alerting design within the COOPANS Eurocat Air Traffic Management System, and to develop better alerting design to assist ATCO's handle safety critical events such as conflict detection and resolution is a safer more efficient manner. Based on the above literature review, current research will investigate the interaction effect between alerting designs (acoustic vs. semantic alert) and working experience (expert vs. novice) on air traffic controller's response time. The third null hypothesis is "H_0: there is no significant interaction effect of alerting design and working experience on ATCO's response time"; and the alternative hypothesis is "H_1: there is significant interaction effect of alerting design and working experience on ATCO' response time".

In the context of the COOPANS system where all three critical alerts are signalled in the same manner, this may delay an ATCO's problem identification phase and consequently delay the development of resolutions for critical events, it may also have a negative impact on ATCO's performance in conflict detection and resolution (Schuster & Ochieng, 2014). In order to predict motion and project aircraft position into the future, aircraft moving forward must be used as basis for a cognitive projection model, and this implied that longer and more frequencies of fixations were devoted to processing all relevant information. Although good performance was maintained in conflict trails with respect to no conflict trials, greater workload was experienced and measured (Marchitto et al, 2016). Alert activations are known to have a negative effect on the primary task, through the startle effect, which is manifested by increased workload, prolonged time for decision making, and reduced situation awareness all of which can contribute to human error. (Baile, Konstan, and Carlis, 2001; Imbert et al, 2014). Design of alerting systems require designers to balance the prominence of the alert and the ease of assimilation into the user's primary task (Maglio and Campbell, 2000). Current research is to investigate the effectiveness of the alerting designs within the COOPANS Eurocat System. The research objectives are to capture best practice for alerting design (acoustic design vs. semantic design) through controllers' response time to critical events; to evaluate the conflict resolution time between different experience levels of controllers (expert vs. novice); and to investigate the interaction effects between alerting design and controllers' experience on response time for resolving the potential conflicts.

2.2 Method

2.2.1 Participants

Seventy-seven participants all currently rated Air Traffic Controllers from Irish Aviation Authority, consisting of fifty-eight males and nineteen females took part in the experiment. The approval of Science and Engineering Research Ethics Committee of Cranfield University was granted in advance of the research taking place. All collected data was only available to the research team and was stored in accordance to the University's Ethical Code and the Data Protection Act.

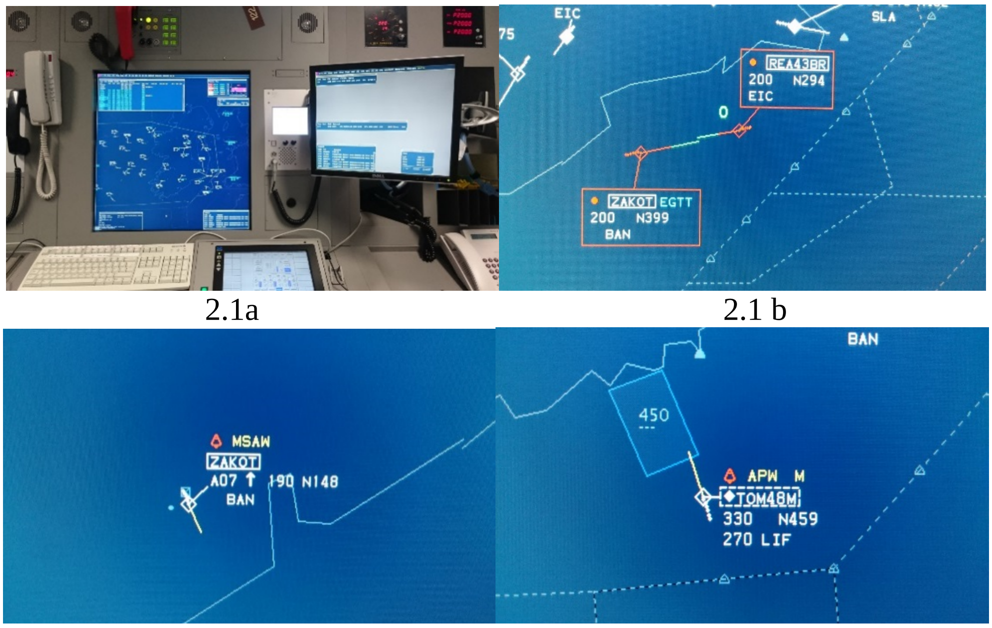
2.2.2 Apparatus

Training Simulator: The Irish Aviation Authority's contingency and validation platform was used to develop the scenarios for STCA, MSAW and APW alerts for current research.

This training platform is an exact copy of the COOPANS Air Traffic Management System. The platform was supplied by THALES Air Traffic Management Systems as part of the COOPANS programme (figure 2.1a). The software version used was known as THALES-B2.1. No adjustment was made to the configuration of acoustic alert presentation within the COOPANS system, the audio alert (Beep-Beep-Beep-Beep) is referred to as the current acoustic alerts for STCA, APW and MSAW. In addition, a semantic alert presentation using a text to speech program used to convert the specific alert nature to spoken word was developed. In this trial a female voice, "Crystal", in English was used as the computer voice for 3 scenarios, such as Beep-Conflict-Conflict-Beep for STCA; Beep-Altitude-Altitude-Beep for MSAW; and Beep-Airspace-Airspace-Beep for APW. The durations of both semantic alerts and acoustic alerts are the same, as ATCOs' response time was measured relative to the onset of the alert.

2.2.3 Scenarios Presented

In order to provide participants with a high fidelity setting, simulated traffic scenarios were developed using the COOPANS training simulator. The trials were faithful to normal operational configuration, all systems were shown to be operating normally, there was no degradation of weather conditions, and all of the aircraft within the training exercises were airlines and aircraft common to Irish airspace. Current Air Traffic Control Training exercises were used to produce events which would trigger the activation of the COOPANS system safety alerts of STCA, MSAW and APW.



2.1a 2.1 b

2.1c 2.1d

Figure 2.1 Examples of the critical events displayed on COOPANS Eurocat Air Traffic Management system

Note: a = Air Traffic Controller Working Position, b = Activated STCA Alert,
c = Activated MSAW Alert, d = Activated APW Alert

2.2.3.1 Short Term Conflict Alert (STCA)

The airspace sector used represented an approach sector, with the radar range set to 40 nm and traffic arriving to and departing from an aerodrome in the centre of the display. A total of 18 aircraft were present in the airspace sector displayed. The STCA is to anticipate positional conflicts within a given airspace and to generate warnings for all eligible system track pairs whose separation is expected to be lower than the defined minimum separation requirement of 1,000 ft vertical separation and three nautical miles lateral separation. A pair of tracks in conflict means that the vertical and horizontal separations are infringed. The visual representation of the STCA is shown as figure 2.1b.

2.2.3.2 Minimum Safe Altitude Warning (MSAW)

The airspace sector used represented an approach sector, with the radar range set to 40 nm and traffic arriving to and departing from an aerodrome in the centre of the display. A total of 18 aircraft were present in the airspace sector were displayed. This alert is intended to alert when any aircraft is infringing or predicted to infringe the relief or minimum sector altitude. It is also designed to predict if an aircraft is projected to deviate from the approach path of an airport. The visual representation of the MSAW is shown as figure 2.1c.

2.2.3.3 Area Proximity Warning (APW)

The airspace sector used represented an approach sector, with the radar range set to 40 nm and traffic arriving to and departing from an aerodrome in the centre of the display. A total of 18 aircraft were present in the airspace sector were displayed. This alert provides a warning that an aircraft is foreseen to enter a Military Operating Area, Danger Area or Prohibited area. The visual representation of the APW is shown as figure 2.1d.

2.2.4 Research Design

Participants were advised that the trials were in relation to operating the COOPANS Air Traffic Control System and were of approximate 30 minutes duration. Participants were advised that on hearing the audio alert sound they should mark on the radar screen shot the aircraft or aircrafts that were creating the alerting event. The commencement of each trial would be announced by the facilitator. When it was confirmed that the participant understood the processes of the trial, the experiments commenced. Each participant completed three scenarios related to radar screen shots of STCA, APW, and MSAW. Simultaneously, once the participant advised they were ready to begin, the appropriate audio sound (either current COOPANS acoustic alert or Semantic Alert) was activated on Toshiba Portege R830-138. Activation of the recording time was synchronised with the activation of the alert, and the response time was recorded upon correct response to the alert. This process continued until all three scenarios of radar screen shots had been completed. Each participant encountered occurrences of STCA, APW, and MSAW randomly in order to eliminate practice effects. The audio alert presented to the Air Traffic

Controllers in trial-A is the acoustic alert that is available within the COOPANS system (Beep-Beep-Beep-Beep). The semantic alert of Trial-B consisted of a new semantic audio alert (Beep-Conflict-Conflict-Beep). A three-way mixed-design ANOVA with ATCO's response time as the dependent variable was conducted. Alerting design (acoustic alert vs. semantic alert) and experience level (novice vs. expert) were two between-subject factors. Considering the generalizability, two designs were assessed in three scenarios (STCA, APW & MSAW). Scenarios were the within-subject factor. A full factorial design was implemented while evaluating interactions among factors. The adjusted degree of freedom was based on the result of Mauchly's test. Significant level was set at $\alpha = .05$ for all analysis. Bonferroni tests were performed to identify pairwise differences for factors with more than two levels. Partial eta-square ($\eta 2$) is a measure of effect size for ANOVA, whereas Cohen's d is an effect size used to evaluate the standardised difference between two means in this study.

2.3 Results

2.3.1 Sample Characteristics

Seventy-seven Air Traffic Controllers participated in the current research, thirty-eight participants completed trials using the current COOPANS acoustic alerts, and thirty-nine participants completed the trials using the semantic alert. Participants' working experience as rated air traffic controllers were between 1 and 40 years ($M = 11.71$, $SD = 8.58$). Thirty-five participants had worked as Air Traffic Controllers for less than ten years and were classified as novices; forty-two participants had worked as Air Traffic Controllers for more than ten years and were classified as experts. Age of the participants ranged from 20 years old to 62 years old ($M = 36.69$, $SD = 8.79$). Response time (seconds) of STCA, APW & MSAW scenarios were collected. Descriptive statistics were showed in table 2.1.

Table 2.1. ATCO's means (standard deviations) of response time of conflict resolution by alerting designs and working experience across three critical scenarios

Alerting design	Experienced levels	*n*	STCA	APW	MSAW
Acoustic	Novice	16	4.87(2.47)	3.13(0.86)	3.24(1.05)
	Expert	22	5.41(3.67)	3.06(0.98)	4.06(3.42)
Semantic	Novice	19	2.46(0.64)	2.60(0.76)	2.46(0.73)
	Expert	20	2.65(0.70)	2.75(0.77)	3.09(1.07)
Total	Novice	35	3.56(2.10)	2.84(0.84)	2.81(0.96)
	Expert	42	4.10(3.00)	2.91(0.89)	3.59(2.60)

2.3.2 Testing main effects and interactions among factors on air traffic controllers' response time

Table 2.2 summarised the result of three-way ANOVA for alerting design, experience, and scenarios. Based on the result of Mauchly's test, the assumption of sphericity was not violated, $\chi^2 = 5.52$, $p = .063$. The results indicated that no three-factor interaction (alerting designs × experience levels × scenarios), $F(2, 146) = 0.196$, $p > .05$. No significant interaction between working experience and scenarios, $F(2, 146) = 0.956$, $p = .39$. No significant interaction between alerting designs and working experience, $F(1, 73) = 0.032$, $p = .86$. Therefore, the third null hypothesis (H_0: the interaction of alerting designs and working experience would have no effect on ATCO's response time) was not rejected. In summary, the design of the semantic alert significantly reduced ATCO's response time for both expert and novice (figure 2.2).

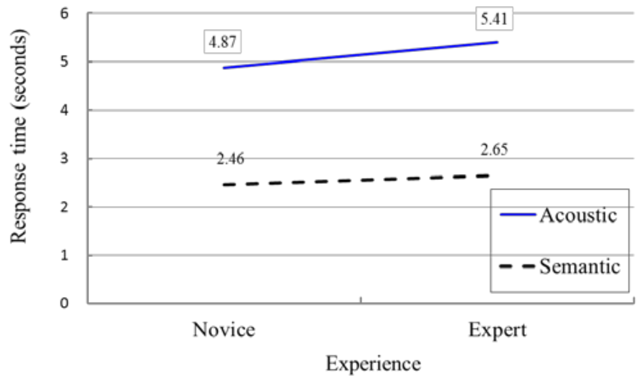
Table 2.2. Three-way analysis of variance for alerting design, experience, and scenario

Source	df	SS	MS	F	*p*	η^2
Between-subject factor						
Design	1	31.713	31.713	17.356	< .001	0.192
Experience	1	2.680	2.680	1.467	0.230	0.020
Design × Experience	1	0.059	0.059	0.032	0.857	< .001

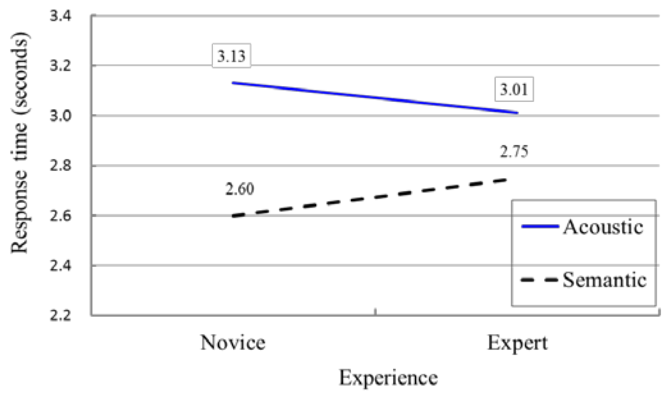
Residual	73	133.387	1.827			
Within-subject factor						
Scenario	2	36.525	18.263	7.892	< .001	0.098
Design × Scenario	2	49.180	24.590	10.626	< .001	0.127
Experience × Scenario	2	4.424	2.212	0.956	0.387	0.013
Design × Experience × Scenario	2	0.784	0.392	0.169	0.844	0.002
Residual	146	337.864	2.314			

Note: df: degree of freedom, SS: sum of square, MS: mean square, η^2: partial eta square

STCA



APW



MSAW

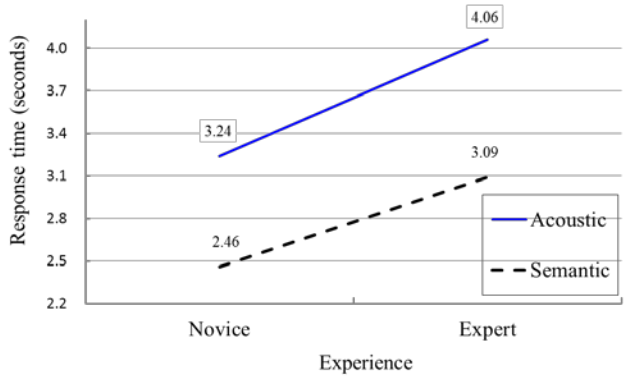


Figure 2.2. ATCO's response time significantly reduce by semantic alert compared with acoustic alert on STCA, MSAW and APW, respectively.

However, a significant interaction between alerting design and scenario was revealed, $F(2, 146) = 10.626$, $p < .001$, $\eta 2 = .127$. A significant simple main effect for the design within the STCA scenario revealed ATCOs required more time in response to acoustic alert (5.182s) than semantic alert (2.562s), $F(1, 75) = 25.142$, $p < .001$, $\eta 2 = .251$. Also, a significant simple main effect for the design within the APW scenario revealed ATCOs required more time in response to acoustic alert (3.091s) than semantic alert (2.677s), $F(1, 75) = 4.662$, $p < .05$, $\eta 2 = .059$. A significant simple main effect for the design within the MSAW scenario revealed ATCOs required more time in response to acoustic alert (3.712s) than semantic alert (2.779s), $F(1, 75) = 4.124$, $p < .05$, $\eta 2 = .052$. In summary, the semantic alert is promising in efficiently conveying crucial message to ATCOs (figure 2.3).

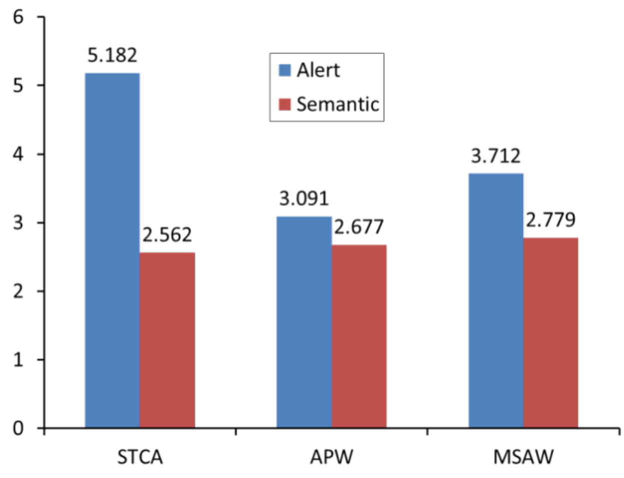


Figure 2.3 Comparison of ATCO's response time among two alert design within three scenarios.

For the alerting design, a significant main effect was found, $F(1, 73) = 17.356$, $p < .001$, $\eta 2 =.192$Air traffic controllers required more time in response to acoustic alert (3.961s) than semantic alert (2.669s). Therefore, the first null hypothesis (H_0: Designs of alert would have no effect on ATCO's response time) was rejected. The main effect of experience is not significant, $F (1, 73) = 1.476$, $p > .05$. Therefore, the second null hypothesis (H0: Working experience would have no effect on ATCO's response time) was not rejected. The scenario did have a main effect on ATCO's response time, $F (2, 146) = 7.892$, $p < .001$, $\eta 2 =.098$. The results of Bonferroni post-hoc comparison indicated that the mean response time for STCA (3.849s) was significantly longer than that in APW (2.886s), $t = 3.733$, adjusted $p < .001$. There was also a trend that the response time for STCA (3.849s) was longer than MSAW (3.209s), $t = 2.397$, adjusted $p = .05$.

2.4 Discussion

In the COOPANS Air Traffic Management System where all three critical alerts are signalled in the same manner "Beep-Beep-Beep-Beep", activated alerts may confuse problem identification and consequently delay ATCO's problem-solving strategies to deal with different critical events. Strauch (2004) proposed that high workload, competing task demands, and ambiguous cues can all contribute to an operator's loss of SA, even with experienced and well-trained operators. A key prerequisite of conflict detection and resolution is the capability to guarantee situation awareness amongst relevant stakeholders in order to optimise safe air traffic flows (Schuster & Ochieng, 2014). ATM specialists have clearly defined situation assessment as the process by which the state of situation awareness is achieved (Sarter & Woods, 1994). There is a need to improve air traffic controllers' situational awareness by designing human-centered alerts in response to critical events.

2.4.1 The design of semantic Alert Significant reducing ATCO's response time

Based on statistical analysis, there are significant differences in ATCO response time between acoustic alert and semantic alert consistently across STCA, and APW (table 2.1). The current COOPANS acoustic alert only provides an auditory stimulus by an activated "Beep" to signal "something critical happening", thereafter ATCO's have to figure out what is causing the critical situation and identify exactly what alert was activated among STCA, or APW in order to develop an appropriate resolution strategy. All of these processes present a risk that an incorrect judgment of the type of alert being signalled could result in the application of an inappropriate resolution strategy. Therefore, the acoustic alert only provides level-1 SA for ATCO's, i.e. they perceive the activated critical event (Endsley, 1995). Despite, high intensity auditory alerts can draw the operator's attention, the alerting effect can also be annoying and lead to controllers being startled thereby further delaying efficient responses (Marshall, Lee, & Austria, 2007).

A poorly designed acoustic alert can distract the operator, decrease situation awareness and subsequent continuous signalling of the alarm can not only disrupt the resolution of the critical situation but also reduce the operator's ability to manage workload (Banbury et al, 2001). By contrast, the newly designed semantic alert provides ATCO's with an initial BEEP to signal "I have an important message for you", following by provided the nature of the alert, i.e. CONFLICT, AIRSPACE or ALTITUDE. The ATCO's can no longer be startled by the activation of the audio warning and as the enhanced design of alert is now more semantically rich and is informing the ATCO precisely the nature of the critical problem, no further cognitive load of evaluating the characteristics of the current situation is required, the ATCO can immediately begin to develop resolution strategies suitable to the specific critical event, thereby providing crucial extra time in a time-limited situation to deploy the most appropriate resolution response. Although solid evidence shows that semantic alert outperforms the acoustic alert across three scenarios, based on the effect size (partial eta square), we did observe that the semantic alert has a better / more efficient effect in STCA ($\eta 2$ = .251) than that in either APW ($\eta 2$ =.059) or MSAW ($\eta 2$ =.052). Given our experiment was not counterbalanced, we cannot exclude the possibility that the ordinal effect (period effect) exists. Another possibility is that the three scenarios did not occur evenly (roughly the occurrences of STCA, APW and MSAW are 92%, 6%, and 2% respectively), therefore the rates of occurrences might have an impact on the effect of semantic alert across three scenarios.

2.4.2 Human-centred design improving ATCO's situation awareness

The results demonstrate that the semantic alert has improved ATCO's situational awareness as a result of a more meaningful salient alert. The design of the semantic alert significantly decreased ATCO's response time by not only presenting salient signals (perceive the alert, level-1 of SA), but also providing ATCO's with knowledge of the nature of the situation to be resolved (understanding current situation, level-2 of SA). Therefore, ATCO's have more time to project the evolving flow of aircraft in the near future (projection of future status, level-3 of SA), and develop more effective resolutions to critical events, permitting a more rapid return to ensuring the rest of the aircraft under his/her control continue to be managed in a safe and efficient way (Endsley, 1997). There is no significant effect on ATCO response time between novice and experienced controllers consistently across STCA, APW and MSAW (Table 2.1), suggesting the semantic design outperforms the acoustic design for both novice and expert air traffic controllers.

Based on table 2.1, ATCO's response time on STCA showed the most noticeable difference between acoustic alerts and semantic alerts. This is an interesting finding that may be a difference in the processing resources required for comprehension of alert on each scenario. For instance, the figure (2.1b) suggest that by default the STCA is an acoustic-only warning that requires the operator understanding the depicted relationship between two aircraft, as the STCA screen does not explicitly show "STCA." However, in the other two scenarios (MSAW, figure 2.1c; APW, figure 2.1d), there is an explicit notation of the warning type present on the screen as "MSAW" or "APW," and these types of warnings only involve a single aircraft (not the relationship among two aircraft). Because the STCA warning type does not explicitly show the warning type on the screen, and it is complicated by having to understand the relationship between two aircraft, it may require more cognitive resources toward resolving the nature of the warning. Because of this, the semantic alert might prove most beneficial in this condition. Furthermore, the semantic alert can promote a better understanding of technology-mediated interaction in ATM systems, as it offers specific information across the ATM systems that influence ATCO's cognitive processes from perception to action by providing the representation and projection of air traffic information. The improvement of ATCO's response time is related to the more human-centered design of the semantic alerts, as it provides ATCO's with knowledge of the critical situation occurring. This is achieved by ensuring that the semantic alert is sufficiently salient (initiated by Beep) so that the attentional mechanism and perception process is engaged, followed by the precise nature of critical event (verbal instruction of CONFLICT) reducing the requirement to revert to working memory as there is no necessity to interpret the activated alerts. The results of current research demonstrated that both novice and expert ATCO's response time were significantly reduced in the response to the semantic alert compared with acoustic alert of COOPANS.

2.4.3 Semantic design off-loading ATCO's working memory

The design of the semantic alert has demonstrated a significant main effect of reducing ATCO's response time for both experts and novices across three scenarios. Embedded within many advanced technologies are sophisticated auditory alarms, aimed at drawing the attention of ATCO's to an event of concern. The fundamental issue is that a poorly designed audio alert system has the potential to annoy and distract the operator, to disrupt the tasks that the operator is engaged in and to prolong information processing. All of these have the potential to prevent the operator accurately identifying, prioritising and responding to abnormal conditions despite the presence of an alerting system designed to enhance safety and assist in retrieving a critical situation (Wood, O'Brien & Hanes, 1987). The human-centered design of the semantic alert provided to ATCO's in this experiment provided them with knowledge, allowing them to react rapidly and accurately in an information rich environment. Furthermore, the semantic alerts were easily distinguishable from each other. The risk of an operator being induced into an error when systems use the same signal to annunciate a number of different alerts is eliminated (Allendorfer, Friedman-Berg & Pai, 2007). To summarise, current research results, semantic alerts could alleviate the expertise differences between novice and expert of ATCO's by promoting quicker response time to critical events regardless of working experience. It is obvious ATCO's response time is primarily influenced by the design of the alerting schemata, as the design of semantic alert facilitated ATCO's information processing and provided them with specific knowledge in the form of mental model needed by controllers. This semantic alert is proposed as a method for improving ATCO situation awareness by providing for the integration and comprehension of information and facilitating the projection of future status (the higher levels of SA), thus significantly off-loading ATCO's working memory and efficiently directing cognitive processes.

2.5 Summary

Technology development within Air Traffic Management continues at a pace with substantial programs underway in both Europe through Single European Sky ATM Research and in the United States through Next Generation Air Transportation System. Both programs aim to revolutionise air traffic management provision through advanced technologies. Consequently the requirement to provide air traffic controllers with human-cantered design of alerts which are appropriately salient and accurate response to critical situations in order to minimise the side-effect of startle should be of primary importance. The results of current research demonstrated that the acoustic alert of COOPANS provides level-1 of SA to ATCO compared with the enhanced semantic alert providing not only level-1 of SA (perception of the alert), but also level-2 of SA assisting ATCO understanding the nature of critical event for developing quick solutions. Consequently, the design of enhanced semantic alert can significantly reduce ATCO's response time across STCA, APW and MSAW. The use of semantic alerts as part of the COOPANS Air Traffic Management system saved ATCO's response time by providing the nature of the critical situation, therefore providing valuable extra time in a time-limited situation. Furthermore, semantic design could alleviate the expertise differences between novice and expert of ATCO's by promoting quicker response time to critical events regardless of level of expertise. The findings of current research indicate that a single training program integrated with human-centered design of semantic alert could improve both novice and expert ATCO's situational awareness and significantly reduce response time to critical events. This represents significant benefit to the air navigation service provider to reduce training cost. An increasing in air traffic sector capacity allows improved ATCO productivity, initial estimates put this productivity improvement at 1% annually. This represents a saving of €2,728,337 per annum across all five COOPANS Air Navigation Service Provider's or €13,641,685 over EU SES RPII (Eurocontrol ACE, 2013). The fact that the critical situations are being resolved more safely and efficiently means that ATCO can resume normal operations within the rest of the air traffic control sector sooner. Overall this is foreseen to possibly enable increased capacity within sectors. Civil Aviation Authorities, Air Navigation Service Providers and Air Traffic Management system providers would have benefits from the findings of current research with a view to ensuring that Air Traffic Controllers are provided with the most optimal alerting schemes to increase their situational awareness and performance to handle the unforeseen critical events.

2.6 Future Application

The semantic alerting design of the COOPANS Air Traffic Management has the potential to save ATCO's response times to critical situations, providing more time for solution generation and improving the likelihood that the most appropriate resolution strategy will be deployed. The findings of current research provides a means for assessing the benefit of design concepts (acoustic alert vs semantic alert) by the context of the full industrial-scale system (COOPANS Air Traffic Management System) and employed trained operators (licensed Air Traffic Controllers) under realistic conditions (STCA, APW and MSAW), creating a rich level of information related to ATCO's performance. From professional perspective this is a valuable finding, as it indicates that a single training program can be developed and provided to both novice and expert ATCO with a result of improving safety performance and quicker response time to critical situations. The applications of current research not only could reduce ATCO's training cost for Air Navigation Service Providers, but also Air Traffic Management System providers would have benefits from ATCO by provided with the most optimal alerting schemes to increase their situational awareness and performance to ensure aviation safety.

CHAPTER III

The Impact of Alerting Designs on Air Traffic Controller's Eye Movement Patterns and Situation Awareness

3.1 Introduction

The majority of alert activations in the COOPANS Air Traffic Management (ATM) system are Short Term Conflict Alert (STCA: A warning system designed to support air traffic controllers in preventing collision between aircraft.) which represent 61% of all activated alerts and include 12% of false alerts (Irish Aviation Authority, 2016). The COOPANS system is deployed in five countries within Europe: Ireland, Denmark, Sweden, Austria and Croatia. ATCOs across these five countries operate a harmonised system which offers three critical alerts using the same acoustic alerting schema in support of the Single European Sky (Eurocontrol, 2015). The COOPANS system provides three kinds of alerts which are designed to support air traffic controller's (ATCO) decision-making during critical situations such as conflict between aircraft (STCA), conflict between aircraft and terrain (Minimum Safe Altitude Warning - MSAW), and conflict between aircraft and airspace where airspace activities which are a risk to civil aviation exist (Area Proximity Warning - APW). Activation of any of these three alerts, signalled by a simple acoustic-designed alert (Beep-Beep-Beep-Beep) indicates either a potential conflict of two aircraft (STCA), conflict between aircraft and prohibited airspace (APW) or conflict between aircraft and terrain (MSAW). The ATCO is then expected to judge and resolve the potential conflict as quickly as possible to prevent an incident or accident (Kearney, Li, & Lin, 2016).

The activation of the STCA alert on the COOPANS system provides a 90-second warning, that unless appropriate action is taken by ATCOs to resolve the conflict, significant risk of collision between aircraft exists. If the ATCO does not detect this alert and does not issue control instructions to flight crew to resolve the conflict, there is a risk of aircraft collision. In the current COOPANS ATM system an activation of a STCA alert might be misinterpreted as another alert such as APW or MSAW due to the same acoustic stimulus. This may delay an ATCO's problem identification thereby weakening ATC safety barriers. Therefore, the auditory alarms should be easily distinguishable from one another by varying frequencies and modulation (Ahlstrom, 2003a).

In Air Traffic Management, a STCA represents a critical event which might lead to a significant air safety event. The mid-air collision that occurred at Überlingen in 2002 involving a B757 and TU154M aircraft was a STCA-related major accident that resulted in 71 fatalities. It occurred in part because an imminent separation infringement was not noticed by an ATCO in time (German Federal Bureau of Aircraft Accidents Investigation, 2004). Previous research found that fixation trajectory could be a key component to situation awareness (SA) (Ratwani, McCurry, & Trafton, 2010); the number of fixations might be associated with the process of SA recovery from interruption (Gartenberg et al, 2014); fixation duration could be an indicator of cognitive process related to task performance (Moore & Gugerty, 2010) and shorter fixation duration indicated higher workload and increased temporal pressure (Causse et al, 2016). Hence, visual monitoring and storage of aircraft information is an important task for an air traffic controller. This requires prompt and accurate responses by the ATCO to resolve the potential risks under time pressure.

3.2 Literature Review

A salient alert might be excellent at attracting operator's attention; however, it may divert an ATCO's attentional resources away by inducing startle. ATCO's cognitive resources may be allocated from the decision-making process to monitoring the flow of time as part of a coping strategy under time limited situations (Zakay, 1993). Furthermore, time pressure might cause the screening phase of problem identification to become less systematic. Therefore, inappropriate alerting design presents many disadvantages and creates potential risks which can lead to accident/incidents, including startle, loss of situation awareness, and switching the human operators outside system control loop (Durso, Truitt, Hackworth, Crutchfield, & Manning, 1998). A number of safety concerns have been identified in ATM systems including a lack of uniqueness of alarms, frequent false alarms, alarms that are not intuitive, annoying alarms which increase workload (Ahlstrom, 2003b; Newman & Allendoerfer, 2000). In addition, inattentional deafness is promoted by cognitive load which might impact ocular measurements, and the key factor of inattentional deafness was generated by the mental calculation of heading or by the numerous tasks required to manage an ATC sector (Causse et al, 2016). These issues can lead to human operators switching from proactive monitoring to reactive controlling such as checking or diagnosis of the risks, potentially resulting in delays to responding to a time critical situation (Dorner, 1993). Therefore, it is necessary to acquire visual information efficiently into the cognitive process via the monitoring work of ATCO. Eye movements can reflect monitoring behaviours (Bruder, Eißfeldt & Hasse, 2014).

3.2.1 Eye Movement Patterns and Situational Awareness

Aviation human factors experts have defined situation awareness (SA) as a state of the individual, and situation assessment as the process by which the state of awareness is achieved in order to conduct timely decision-making (Li, Harris, & Yu, 2008; Sarter & Woods, 1994). Furthermore, Endsley (1997) developed a situation awareness and decision-making framework which is based on the information-processing model, and defined SA 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 future' to perform appropriate decision-making. Managing complex ATM systems including minimising response time to critical alerts such as STCA is not only an issue of technical skill, but also of a real-time decision-making involving situation awareness under time pressure. More recently, an analysis of military aviation accidents found perceptual errors and loss of situation awareness were involved in many aviation accidents (Diehl, 1991; Li et al., 2014). However, the definition of SA has lots of important differences in what constitutes SA compared with Endsley's SA framework.

Dekker and Hollnagel (2004) proposed that SA has the characteristics of a folk model with no explanatory power. There is a magnitude of discrepancy between Endsley's reported 88% of accidents/incidents attributed to SA problems and 1.4% identified SA issues based on the Aviation Safety Reporting System (ASRS) (Vaitkunas-Kalita, Landry, & Yoo, 2011). There are lots of arguments on the 'construct of situational awareness' and the 'meaning of loss of situational awareness' in the domain of Human Performance (Dekker, 2001; Dekker & Hollnagel, 2004; Stanton et al., 2006; Stanton et al., 2017). How information is presented is highly critical to its readability, understandability, and accessibility, thus impacting on human perception, cognition and performance. There is a continuing need to conduct objective research on Endsley's model of SA, as some of the disagreements result probably by misconception and misunderstandings of the model of SA (Endsley, 2015).

Eye movements are closely linked with visual attention and can be analysed to explore how much effort and shifting attention occurred whilst performing visual tasks (Kowler, 2011). Previous studies indicate that human's fixations are not attracted by salient objects, but rather the meaningful places for the task that is being undertaken (Henderson, 2003). Fixation duration comes from deliberate consideration and induces more fixation points for acquiring more detailed information (Schulte-Mecklenbeck, Kuhberger, & Ranyard, 2011).

Saccade is defined as fast eye movement and generally it declines as a function of increased mental workload, while the pupil diameter increases as a function of cognitive demand (Ahlstrom & Friedman-Berg, 2006). Saccadic eye movements are controlled by top-down visual processes, which are coordinated closely with perceptual attention (Zhao et al., 2012). The path of saccades is associated with selective attention and accurate judgments for perceptual targets (Henderson, 2003). ATCOs not only have to distribute their attention to detect potential conflicts among aircraft both in the air and on the ground, but also have to resolve unexpected events under time pressure through radio telephony communications with pilots. SA may be achievable without knowing what to do in some situations; however, understanding can require awareness of an event prospect including outcomes and preconditions of action (Lundberg, 2015). Therefore, visual attention is a precursor to initiating the cognitive process involved in attention distribution, situation awareness, and real-time decision-making (Lavine et al., 2002).

3.2.2 Alerting Designs Impacted to Attention Distribution

The definition of conflict in ATM is 'an event in which two or more aircraft experience a loss of minimum separation, the distance between aircraft violates a criterion of 5 miles lateral distance or 1,000 feet of vertical distance'. The goal of decision support systems for conflict detection and resolution is to present warning messages to ATCOs predicting a conflict in sufficient time to respond and prevent any erosion of safety standards. Conflict detection can be assumed as the process of deciding when action should be taken, and conflict resolution involved in determining what actions should be performed. Therefore, an ATCO can have more time to conduct problem-solving in advance (Kuchar & Yang, 2000). However, the current COOPANS ATM system has a simple acoustic design (Beep-Beep-Beep-Beep) which signifies one of three different critical hazards: STCA for conflict; MSAW for terrain; and APW for airspace. This design had induced ATCO's into startle and also into misinterpreting the type of critical alerts being presented, and in the worst circumstance, the ATCO’s response may be to solely silence the acoustic alert due to distraction. Better designed acoustic alerts are not necessarily the answer. Whilst they may be outstanding at seizing the ATCO’s attention, the alert may immediately divert the ATCO’s attention away from the ongoing task, incurring other issues such as startle and operational error by distraction (Imbert et al., 2014).

The term of SA has been criticised as poorly defined and extremely debatable as a folk model, e.g. deficient SA was a causal factor resulting in accidents (Billings, 1995; Dekker & Hollnagel, 2004; Stanton et al., 2006). Furthermore, the prevailing notions of SA are overgeneralised such that those related perceptual factors, e.g. experience and workload, impacting SA performance are easily ignored. In addition to audio intensity warning, the semantic content of an auditory alert conveying the specific risk is the central component to alleviate time pressure and promote more effective decision-making (Edworthy & Hellier, 2006). Appropriate design of decision support tools in ATM systems can assist in moderating ATCO workload and improving SA by facilitating a better match between task demand and cognitive resource (Kaber et al., 2006). Designing decision support systems for ATCO’s requires an understanding of principles of cognitive system engineering and allocation of function and team adaptation. It is a holistic approach of distributed cognition coordination to rapidly changing situations (Langan-Fox, Canty, & Sankey, 2009).

Future human-centred designs of ATM systems must be based on a strategic, collaborative and automated concept of operations, as high performance in monitoring tasks has the potential to increase both airspace efficiency and the safety of aviation (Schuster & Ochieng, 2014). As detailed in the proposed paper the use of decision support systems “for conflict detection” is to provide advanced notice of a real, unsafe situation should the ATCO not intervene or take actions. ATM system functionalities such as Medium-Term Conflict Detection (MTCD), STCA and Trajectory Prediction (TP) belong to a suite of COOPANS tools called “safety nets”. As detailed in the ATM master plan safety net enhancements will “maximise the future ATM system’s contribution to aviation safety and minimise its contribution to the risk of accident”. The deployment of a semantic alert for STCA events for example would reduce ATCO cognitive workload as it is argued that ATCOs will process the alert faster than the generic Beep Beep Beep acoustic alert.

3.2.3 Visual Behaviours Reflecting Information Processing

Human-centered design can improve an ATCO’s performance and reduce their cognitive workload (Laois & Giannacourou, 1995), giving the ATCO increased cognitive capability to perform complex tasks (Tobaruela et al., 2014; Wickens & Hollands, 2000). If a controller over-relies on automated systems, it might result in poor SA (Orasanu, 2005). The concurrence of excessive fixations, long fixation duration and less saccade duration is the precursor of tunnelled attention (Johnson & Proctor, 2004). ATCO’s visual behaviours provide an opportunity to investigate the relationship between eye movement patterns and information processing. Eye scan pattern is one of the most powerful methods for assessing human beings’ cognitive processes in Human–Computer Interaction (Ahlstrom & Friedman-Berg, 2006). Visual activity is the objective method for assessing an ATCO’s cognitive process related to real-time decision-making (Ayaz et al., 2010). Based on accident investigation, 75% of aviation accidents involved poor perceptual encoding on the flight deck (Jones & Endsley, 1996). This phenomenon highlights how interface design impacts operator’s attention distribution, cognitive activities, situation awareness and decision-making. Authors’ previous research has found that effective context-specified design of alerts, where the warning signal is more than a mere stimulus, where the alert has been integrated to the ATCO’s cognitive system and where the alert provides meaningful information can significantly speed up ATCO’s response (Kearney & Li, 2015; Kearney et al., 2016).

Patterns of eye movement is one of the methods for assessing ATCO‘s cognitive processes based on real-time physiological measures (Henderson, 2003). Auditory alerts can attract an operator’s visual attention regardless of where their visual attention is directed, if the alert is presented at an effective level. However, a side-effect of auditory alerts can be that poorly deployed alerting systems can induce startle and lead to the operator suffering tunnel vision at the cost of all other operations they are engaged in. Semantically designed verbal warnings tailored to specific hazard situations may improve hazard-matching capabilities without a substantial trade-off in perceived annoyance (Baldwin, 2011). ATCOs’ visual search for maintaining SA is affected by the surrounding environment and interface designs. The factors manipulating visual attention include how information is presented, the complexity of the interface design, and the operating environment. These arguments provide a compelling explanation that eye movement is highly correlated with attention, indicating a substantial correlation between attention shifts and maintaining SA to support decision-making. The research objectives are to investigate how alerting design impacted ATCOs’ visual behaviours and situation awareness by comparing their response to acoustic alerts versus a newly designed semantic alert, using the COOPANS ATM system.

3.3 Method

3.3.1 Participants

Twenty-six qualified air traffic controllers from the Irish Aviation Authority (IAA) participated in this research. Participants’ ages ranged between 24 and 47 years old (M=35.15, SD=6.11); professional experience ranged between 1 and 25 years (M=8.56, SD=6.81). Approval of the Science and Engineering Research Ethics Committee of

Cranfield University was granted in advance of the research taking place (CURES/1506/2016). All collected data were only available to the research team and were stored in accordance to the University's Ethical Code and the Data Protection Act.

3.3.2 Apparatus

3.3.2.1 Training simulator

The contingency and validation platform of IAA was used to develop the STCA exercise. This training simulator reflects the same layout with the COOPANS Air Traffic Management System supplied by THALES. The software used was THALES-B2.1 for the configuration of acoustic alert (Beep-Beep-Beep-Beep). The COOPANS Air Traffic Management System is the system which is being used currently in the IAA for air traffic control (Figure 3.1). The semantic alert was developed by an IAA engineer and installed in the training simulator to support this experiment. The semantic alert design philosophy drew on previously established research from industry including airborne conflict detection and alerting systems such as TCAS/ACAS. The alerts were validated on the Technical and Training Facility prior to introduction and were designed as an integrated WAV file which triggered based on system derived criterion for each specific alert under assessment.

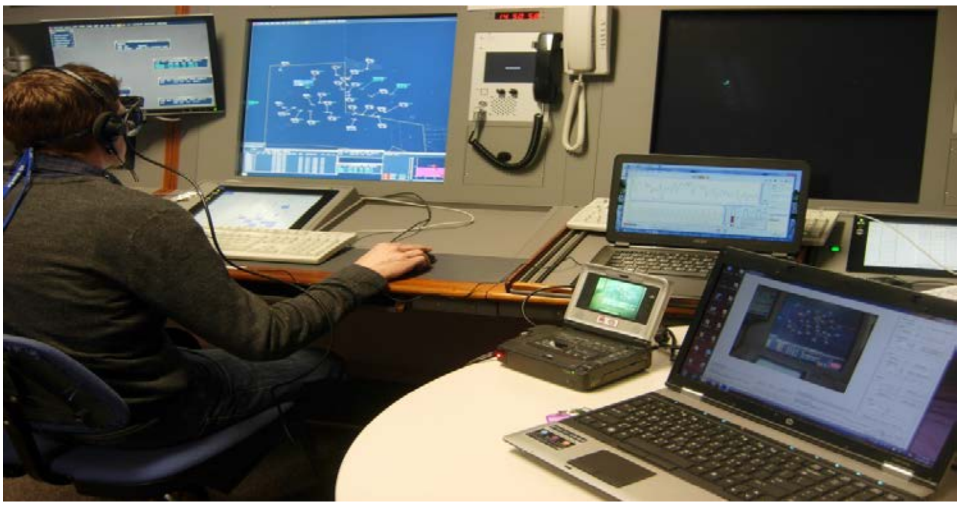
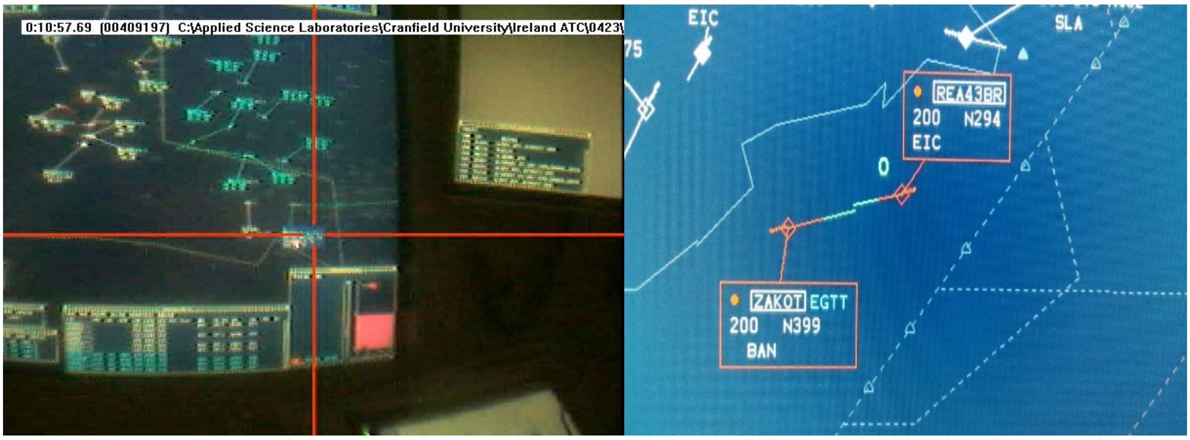


Figure 3.1. Participants conducted the trial by wearing an eye tracker whilst operating the COOPANS ATM trainer

3.3.2.2 Eye Tracking Device

A mobile head-mounted eye tracker (ASL Series 4000) was used to collect ATCO's eye movement data. The sampling rates are between 30 and 60 Hz. The eye tracker is portable and weighs only 76g. Air Traffic Controllers can move their head without any limitations during the experiment. Visual and cognitive science research typically analyse eye movements in terms of fixations (pauses over informative regions of interest), fixation duration (the sum of all durations on fixating an AOI), pupil size (indicator of cognitive load) and saccades (rapid movements between fixations). Therefore, the analysis metrics of this research include parameters of the following visual behaviours, fixation counted, percentage of fixations, fixation duration, pupil size, saccade duration, and saccade velocity.



3.2a 3.2b

Figure 3.2a. STCA alert is triggered (in red circle) by acoustic alert at 90 seconds before the conflict while ATCO's fixation on the red cross position; figure 3.2b shown the presentation of STCA on the COOPANS ATM System

3.3.2.3 Scenarios

The STCA scenario was developed to ensure consistent levels of air traffic reflective of day to day air traffic management within Irish airspace. The simulation included air crew initiated climbs and descents to present crossing traffic and initiate STCA activation, where

climb and descent rates were deliberately inconsistent. The timing of which was randomised and introduced by the instructor. The airspace sector used represented an approach sector, with the radar range set to 40 nm and traffic arriving to and departing from an aerodrome in the centre of the display. A total of 18 aircraft were present in the airspace sector displayed. A target airspace environment representing a busy international airport approach sector was selected as a representative airspace configuration for the experiment. On this basis 1,000ft vertical and five miles lateral separation standard applied as requirements.
The STCA is triggered by positional conflicts within a given airspace for all eligible system track pairs whose separation is expected to be lower than the defined minimum separation requirement of 1,000 feet vertical separation and five nautical miles lateral separation. A pair of tracks in conflict means that the vertical and/or horizontal separations are infringed. The visual representation of the STCA is shown as figure 3.2a and 3.2b a pop-up flashing red boarder activates. Additionally the Radar Position Indicator and flight information also turns red. Conflicting aircraft are tagged with a red ball beside the highlighted callsign on the screen. A standard air traffic control training scenario was modified to contain an unanticipated STCA event. To standardise the processes of data analysis, it was necessary to standardise the time of ATCO’s eye movement due to the varied time frames in performing the air controlling task between 650 and 1035 seconds. Considering the criticality of STCA alerts and their relative occurrence (61% of alerts), two alerting designs (semantic design vs acoustic design) were assessed using an STCA scenario.

3.3.3 Research Design

All subjects undertook the following procedure: (1) briefing about the objectives and procedures of the experiment (10 minutes); (2) calibration of the eye tracking device by using three points distributed over the ATM screen and control panels (5-10 minutes); (3)

participants performed the STCA scenario either by acoustic alert or semantic alert randomly (10-20 minutes); (4) debrief of subject's feedback and comments (5-10 minutes). Each participant took around 50 minutes to complete the experiment. The audio alert presented to the Air Traffic Controllers in trial-A was the acoustic alert that is available within the COOPANS system (Beep-Beep-Beep-Beep). The experiment was conducted within the context of a mature, operational system and aims to explore how a relatively simple change to the alert can provide additional information and speed up decision making. As such, the semantic alert of Trial-B consisted of a new semantic audio alert (Beep-Conflict-Conflict-Beep). All participants were advised that the trials were in relation to operating the COOPANS Air Traffic Control System and were presented randomly with either the acoustic alert or the semantic alert. Participants' operational behaviours such as silencing the alert while STCA warning activated will be recorded for further analysis.

A two-way mixed-design ANOVA with ATCOs' eye movement parameters including fixation numbers, fixation duration, saccade duration, saccade length, and pupil size was conducted. Alerting design (acoustic alert vs. semantic alert) is between-subject factors. For each subject, 60 seconds of ATCOs' eye movement data were analysed - 30 seconds before and 30 seconds after the activated alerts. Those two sessions of eye movement parameters (before and after alert activation) capture the most critical phases in terms of cognitive processes related to monitoring performance based on IAA senior instructors' professional experience. This data was used to compare the characteristics of ATCO's visual attention distribution and situation awareness to different types of alerting designs. The adjusted degree of freedom was based on the result of Mauchly's test. Significance level was set at $\alpha = .05$ for all analysis. No Bonferroni tests were performed to identify pairwise differences for factors, as there are no more than two levels of independent variables. Partial eta-square ($\eta 2\rho$) is a measure of effect size in current study.

3.4 Results

The demographic information of the subjects' age, gender, and working experience are shown as table 3.1. A two-way mixed design ANOVA was applied to analyse five eye movement parameters as dependent variables (fixation count, fixation duration, saccade duration, saccade velocity and pupil size) by two independent factors; the first factor is between-subjects of alerting designs (acoustic design vs semantic design), and the second factor is within-subjects of alerting phases (before alert vs after alert).

Table 3.1. Participants' demographical variables for alerting designs (N=26)

Variables	Groups	Frequencies
Gender	Male	5 (19.2%)
	Female	21 (80.8%)
Age	25-30	7 (26.9%)
	31-35	5 (19.2%)
	36-40	8 (30.8%)
	41 and above	6 (23.1%)
Working Experience (years)	5 and less	11 (42.3%)
	6-10	7 (26.9%)
	11-15	4 (15.4%)
	16-20	1 (3.8%)
	21 and above	3 (11.5%)

3.4.1 Fixation counts

There is a significant main effect of alerting designs on fixation counts (table 3.2), F (1, 24) = 31.35, p < .001, partial η^2 = .193, the result demonstrated that the semantic design had significantly more fixation counts (M = 46.25, SD = 6.19) compared with the acoustic design (M=39.80, SD = 11.16). Also, there is a significant main effect of alerting phases (table 3.3), F (1, 24) = 42.5, p < .001, partial η^2 = .639, before alert activation had significantly more fixation counts (M = 47.38, SD =6.95) compared with after alert activation (M = 40.15, SD = 9.34). Furthermore, there is a significant interaction on fixation counts between alerting designs and alerting phases, F (1, 24) = 5.15, p < .05, partial η^2 = .177. The pattern of interaction shown as table 3.4 and figure 3.3a. Further application of simple main effect analysis revealed there is a significant effect of alerting designs on fixation counts after alert activation, F (1, 48) = 9.47, p < .01, partial η^2 = .189, showing the semantic design significantly increased fixation counts (M = 43.69, SD = 5.31) compared with acoustic design (M = 34.50, SD = 11.73) after alert activation. However, there is no significant simple main effect of alerting designs on fixation counts before alert activation, F (1, 48) = 1.54, p = .22, partial η^2 = .037.

Table 3.2. Summary of eye movement parameters main effects on alerting designs

Variables	Alerting Designs	*SS*	*df*	*MS*	*F*	*p*	η_p^2
Fixation counts	Designs	561.80	1	561.80	31.35	<.001	0.193
	Errors	2353.20	24	98.05			
Fixation duration	Designs	17539.23	1	17539.23	0.883	.357	0.035
	Errors	476977.00	24	19874.04			
Saccade duration	Designs	546750.35	1	546750.35	4.973	.035	0.172
	Errors	2638566.42	24	109940.27			
Saccade velocity	Designs	102761.73	1	102761.73	1.676	.208	0.065
	Errors	1471880.75	24	61328.36			
Pupil dilation	Designs	66696483.83	1	66696483.83	0.585	.452	0.024
	Errors	2736000000.00	24	113996049.42			

Table 3.3. Summary of eye movement parameters main effects on alerting phases

Variables	Alerting Phases	*SS*	*df*	*MS*	*F*	*p*	η_p^2
Fixation counts	Phases	760.85	1	760.85	42.5	<.001	0.639
	Errors	430.08	24	17.92			
Fixation duration	Phases	10692.62	1	10692.62	2.6	.120	0.098
	Errors	98561.30	24	4106.72			
Saccade duration	Phases	352586.81	1	352586.81	12.515	.002	0.343
	Errors	676140.27	24	28172.51			
Saccade velocity	Phases	134435.23	1	134435.23	9.806	.005	0.290
	Errors	329028.33	24	13709.51			
Pupil dilation	Phases	43770578.50	1	43770578.50	14.280	.001	0.373
	Errors	73564523.42	24	3065188.48			

Table 3.4. Summary of interactions between alerting designs and alerting phases of eye movement parameters

Variables	Designs	Phases	*M*	*SD*	*df*	*F*	*p*	*η2p*
Fixations	Acoustic	Before	45.10	7.94	24	5.147	.033	0.177
		After	34.50	11.73				
	Semantic	Before	48.81	6.08				
		After	43.69	5.31				
Fixation duration (msec)	Acoustic	Before	397.27	93.41	24	4.623	.042	0.162
		After	387.63	174.99				
	Semantic	Before	395.85	81.46				
		After	464.65	90.13				
Saccade duration (msec)	Acoustic	Before	273.68	195.56	24	12.395	.002	0.341
		After	611.26	539.88				
	Semantic	Before	231.34	83.70				
		After	232.03	127.08				
Saccade velocity (pixels/sec)	Acoustic	Before	502.19	237.91	24	6.393	.018	0.21
		After	313.35	153.94				
	Semantic	Before	509.23	176.06				
		After	488.94	202.20				
Pupil dilation ($pixel^2$)	Acoustic	Before	23716.91	8512.55	24	0.108	.746	0.004
		After	25438.99	8426.45				
	Semantic	Before	25881.01	7444.76				
		After	27930.65	6767.00				

3.4.2 Fixation duration

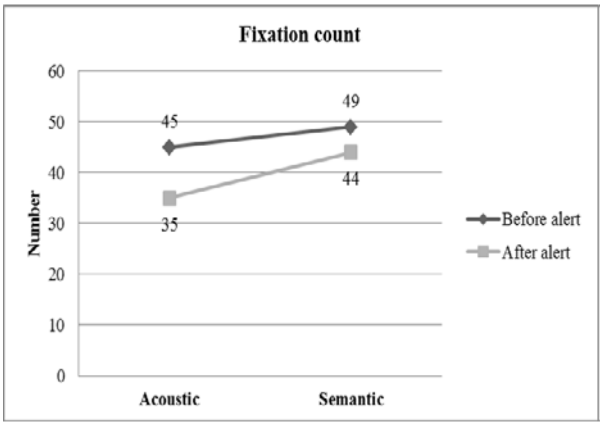
There is no significant main effect of alerting design on fixation duration (table 3.2), F (1, 24) = .883, p = .357, partial η^2 = .035, the result demonstrated that the semantic design (M = 430.25, SD = 91.44) had no significant difference on fixation duration compared with the acoustic design (M = 392.50, SD = 136.62). Also, there is no significant main effect of alerting phases (table 3.3), F (1, 24) = 2.6, p = .120, partial η^2 = .098, the result shows no significant difference on fixation duration between before alert (M = 396.46, SD = 84.40) and after-alert (M = 435, SD = 131.75). However, there is a significant interaction of fixation duration between alerting designs and alerting phases, F (1, 24) = 4.623, p < .05, partial η^2 = .162. The pattern of interaction shown as figure 3.3b and table 3.4. Further application of simple main effect analysis revealed there is no significant effect of alerting designs on fixation duration after alert activation, F (1, 48) = 3.216, $p = .079$, partial η^2 = .075. Also, there is no significant simple main effect of alerting design on fixation duration before-alert activation, F (1, 48) = .001, $p = .972$, partial $\eta^2 = .000$.

3.4.3 Saccade duration

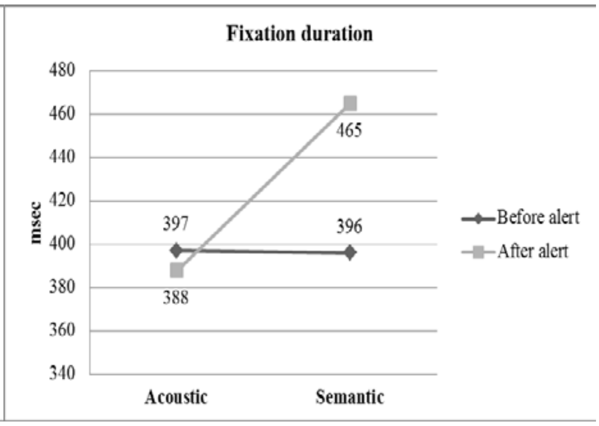
There is a significant main effect of alerting design on saccade duration (table 3.2), F (1, 24) = 4.973, $p < .05$, partial $\eta^2 = .172$, the result demonstrated that the semantic design (M = 231.78, SD = 105.85) had significantly less saccade duration compared with the acoustic design (M = 442.55, SD = 431.50). Also, there is a significant main effect of alerting phases (table 3.3), F (1, 24) = 12.515, $p < .005$, partial $\eta^2 = .343$, the result shown before alert (M = 247.65, SD = 135.69) had significantly less saccade duration than after alert (M = 378.04, SD = 387.32). Furthermore, there is a significant interaction of saccade duration between alerting designs and alerting phases, F (1, 24) = 12.395, $p < .005$, partial $\eta^2 = .341$. The pattern of interaction shown as figure 3.3c and table 3.4. Further application of simple main effect analysis revealed there is a significant effect of alerting design on saccade duration after alert activation, F (1, 48) = 13.54, $p < .001$, partial $\eta^2 = .262$, showing semantic design (M = 232.19, SD = 127.08) significantly decreased saccade duration compared with acoustic design (M = 611.40, SD = 539.88) after alert activation. However, there is no significant simple main effect of alerting designs before alert activated, F (1, 48) = .017, p = .683, partial $\eta^2 = .004$.

3.4.4 Saccade velocity

There is no significant main effect of alerting design on saccade velocity (table 3.2), F (1, 24) = 1.676, $p = .208$, partial $\eta^2 = .065$, the result demonstrated that the semantic design (M = 499.12, SD = 186.78) had no significant difference on saccade velocity compared with the acoustic design (M = 407.75, SD = 217.78). However, there is a significant main effect of alerting phases on saccade velocity (table 3.3), F (1, 24) = 9.806, p < .01, partial η^2 = .290, the result shown before alert (M = 506.50, SD = 197.45) had significantly faster saccade velocity than after alert (M = 421.46, SD = 201.66). Furthermore, there is a significant interaction of saccade velocity between alerting designs and alerting phases, F (1, 24) = 6.393, p < .05, partial η^2 = .210. The pattern of interaction shown as figure 3.3d and table 3.4. Further application of simple main effect analysis revealed there is a significant effect of alerting design on saccade velocity after alert activation, F (1, 48) = 5.35, p < .05, partial η^2 = .120, showing that the semantic design (M = 489.06, SD = 202.20) significantly increased saccade velocity compared with the acoustic design (M = 313.30, SD = 153.94) after alert activation. However, there is no significant simple main effect of alerting design on saccade velocity before alert activated, F (1, 48) = .01, p = .927, partial η^2 = .000.



3.3a



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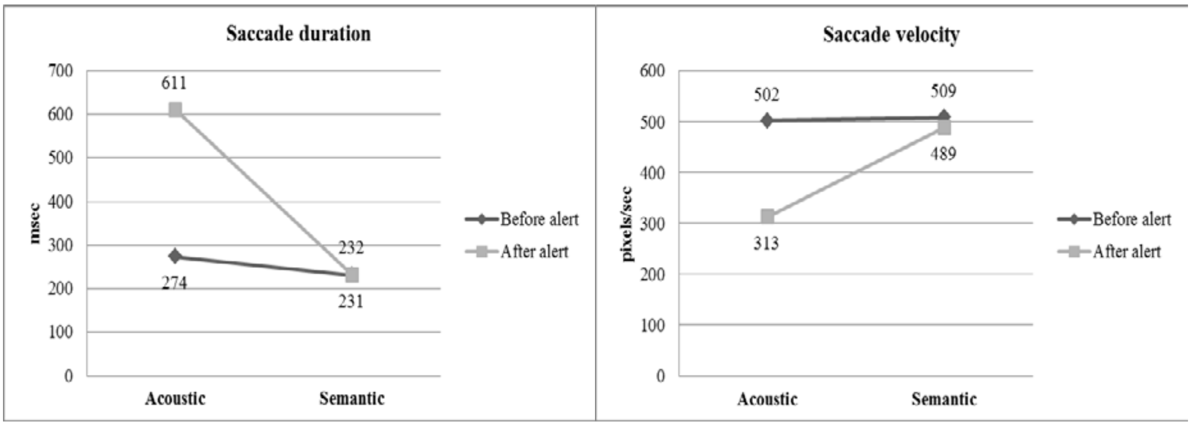

3.3c 3.3d

Figure 3.3. ATCO's eye movement patterns show significant interaction between alerting design (acoustic vs semantic) and alerting phases (before vs after) on (3a) fixation count; (3b) fixation duration; (3c) saccade duration and (3d) saccade velocity

3.4.5 Pupil dilation

There is no significant main effect of alerting design on pupil dilation (table 3.2), F (1, 24) = 0.585, p = .452, partial η^2 = .024, the result demonstrated that the semantic design (M = 26905.84, SD = 7075.31) had no significant difference on pupil size compared with the acoustic design (M = 24577.95, SD = 8290.91). However, there is a significant main effect of alerting phases on pupil size (table 3.3), F (1, 24) = 14.28, p < .005, partial η^2 = .373, the result shows that an ATCO's pupil dilation (M = 26972.31, SD = 7386.84) is significantly bigger than before alert activation (M = 25048.69, SD = 7777.82). There is no significant interaction of pupil size between alerting design and alerting phase, F (1, 24) = 0.108, p = .746, partial η^2 = .004. The pattern of interaction shown as figure 3.4 and table 3.4.

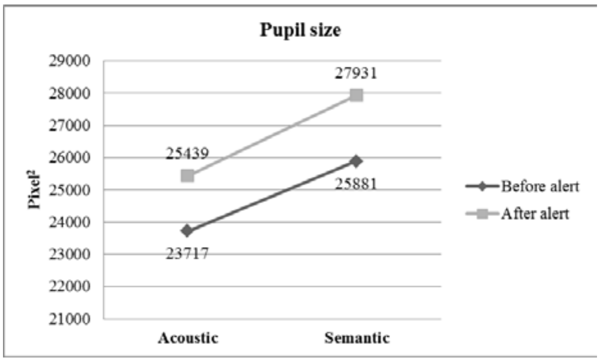

Figure 3.4. ATCO’s pupil dilation shows no significant interaction between alerting design (acoustic vs semantic) and alerting phases (before vs after), however, it has significant difference between before alert and after alert.

3.5 Discussion

Human operators play a critical role across operations, training, design, regulations and safety management. An understanding of human information processing is evidently demonstrated by reduction of human error in the systems (Chang, Yang, & Hsiao, 2016; Honn et al., 2016). The organisation of information for effective decision-making is an emergent theme of human-computer interactions between internal resources and external representations (Hollan, Hutchins, & Kirsh, 2000). The match between internal and external factors is a key prerequisite of monitoring performance. Therefore, an alerting design has to convey specific information to reflect external events in order to improve ATCO’s SA and optimise ATCO’s decision-making (Schuster & Ochieng, 2014). When information is complex, the corresponding eye movement will be different, such as increased fixation duration and reduced saccade distance (Hoffman & Subramaniam, 1995). Evaluating ATCOs’ monitoring behaviours by using dynamic simulations and based on eye movements is an innovation which enables the development of new approaches for assessing selection profiles (Bruder et al, 2014). The results of current research has demonstrated that ATCOs' eye movement patterns had significant differences depending on the phases of alert activated and types of alerting designs.

3.5.1 Semantic Design Effect on ATCO's Situation Awareness

The results revealed no difference on fixation counts before-alerts between acoustic design and semantic design. Interestingly, the semantic design increased significantly the fixation counts compared with the acoustic design after alert activation (figure 3.3a). Furthermore, there is no difference of fixation duration before alert activation between acoustic design and semantic design. However, the semantic design increased significantly the fixation duration compared to the acoustic design after alert activation (figure 3.3b). This implies that the semantic design promotes ATCO's SA by increasing fixation numbers, allowing the ATCO to collect more critical information, and to conduct deliberate cognitive thinking by cumulative fixation duration which is related to problem-solving and therefore to developing conflict resolution strategies. It is reasonable that there are no significant differences between acoustic design and semantic design before alert activation, as an ATCO's cognitive processes are only triggered by the activation of alerts. The results of this research support previous findings that fixation duration reflects the concentration degree in extracting information, and fixation numbers reveal that critical information is processed by ATCO's to gain SA (Kotval & Goldberg, 1998). Theoretically, SA is a key component in human information processing, and is the basis for a proper decision-making (Wickens & Hollands, 2000). Despite SA being highlighted in the aviation domain as an essential prerequisite for safe operations, Sarter and Woods (1991) have challenged the SA technique needed to freeze a simulation of the primary task for probing the operator's situation awareness which clearly does not reflect real world operations. The results indicate that ATCOs have to sustain substantial attention to avoid mis-judging the trajectory of a moving target among lots of dynamic information (Li et al., 2016). In summary, an ATCO's decision-making can be divided as situation awareness (conflict detection) and action choice (conflict resolution). Situation awareness is the starting point for an ATCO's problem-solving in critical situations, as the ATCO cannot solve a problem unless he/she recognises there is a problem and understands the nature of the problem (Orasanu & Davison, 2001; Bruder et al, 2014). ATCO's eye movement patterns demonstrated that the semantic alert design is superior to the acoustic design to promote SA for monitoring performance (table 3.4).

The significant difference in ATCO's saccade duration was observed between acoustic design and semantic design after alert activation (table 3.4). ATCOs saccade duration is significantly decreased by using the semantic design compared to acoustic design (figure 3.3c). This illustrates that the ATCO shifts fixations with shorter time to search for critical information to make appropriate decisions in time-limited situation (90 seconds or less). Furthermore, the results reveal that the semantic design significantly increases saccade velocity after alert activation (figure 3.3d). ATCO's response time is primarily influenced by the design of alerting schemata, as the design of the semantic alert facilitated the ATCO's information processing and provided them with specific knowledge in the form of a mental model. The semantic alert has demonstrated improved ATCO's SA by providing a warning signal and characteristics of risk (level-1 and level-2 of SA), and assisting the projection of future status (level-3 SA), thus significantly off-loading ATCO's working memory and efficiently directing cognitive processes to problem solving (Kearney et al., 2016).

3.5.2 The Design of Context-specified Alert Directing Visual Attention

It has been proposed that semantic memory can have a positive impact on task performance (Gobet, 1998). Before the alert activates, the results show no differences between acoustic and semantic designs, as participants did not receive any stimuli from the ATM system. However, there are significant differences on fixation counts, fixation duration, saccade duration and saccade velocity between acoustic and semantic designs after alert activation. This is the evidence which ATCO's internal information process is significantly influenced by the representation of the alerting design. Based on the recording, eight participants silenced the acoustic alert first when it activated, then moved to resolve the issue. The reason they silenced the acoustic alert is that the auditory warning is annoying and distracts them from their task performance, as ATCOs can't concentrate on logical thinking to develop strategies for conflict resolution due to interruption of the acoustic alert. On the other hand, only two participants silenced the semantic alert - both participants expressed a concern of distraction by the auditory stimulus and they claimed they were already aware of the nature of the problem. ATCO's fixation shifting demonstrated that visual scan patterns related to alerting designs. In addition, before distributing saccades to the STCA conflict, auditory alert attracts ATCO's attention is the bottom-up cognitive process (the perception level of SA). Efficient alert design plays a very important role to activate ATCO's top-down knowledge-based visual process using saccades to survey correctly the potential at risk aircraft and subsequently interact with the visual ATM interface (the comprehension level of SA) and resolve the possible conflicts (the projection level of SA). Therefore, auditory alert design is associated with visual detection which should avoid inducing the occurrence of inattentional deafness (Macdonald & Lavie, 2011; Dehais et al, 2014).

In terms of the long debate on SA term, Parasuraman, Sheridan, and Wickens (2008) recognised the phenomenon of overgeneralising SA. To avoid overgeneralising SA, studies associated with SA should apply high fidelity simulators and design the experimental scenario to reflect and comply with real world operations. As systems become more complex and technology-driven, this raises important questions around situation awareness and how best to support it across individuals, teams, organisations and entire systems (Sarter & Woods, 1991; Stanton et al., 2006; Stanton et al., 2017). Eye-tracking devices have been applied to human-computer interaction domains for a long time, such as flight deck design, controller working position design, and design of control rooms for nuclear power plants (Ahlstrom & Friedman-Berg, 2006; Ha et al., 2006; Tvaryanas, 2004). Quick saccade velocity with the semantic design promotes quick attention distribution when searching for critical information after alert activation in order to enhance situational awareness. Based on the results of saccade duration and saccade velocity, the ATCO's attention, SA and decision-making process are influenced by alerting design within an ATM system. Real-time decision support requires reliable visualisation to evaluate temporal information (dynamic aircraft movement) promptly to predict future status. Therefore, it is important to provide context-specified decision supports for dynamic situations (Ltifi et al., 2015). The semantic design can increase ATCO's cognitive ability by integrating visual resources and auditory signals to direct attention, to improve SA, expand working memory, and to enhance the recognition of patterns compared to the acoustic design. The effective design to improve monitoring performance must take the ATCO's cognitive process into account. The design of the semantic alert directly affects comprehension, as recognition is enhanced when stimuli are processed in a semantically meaningful way (Greve, Van Rossum, & Donaldson, 2007).

3.5.3 The Path of Fixations Reflected to ATCO's Information Processing

Saccade is defined as a quick eye movement between two phases of fixation in the same direction. Fixation shifts demonstrate the attention distribution and scan path of operators (Ratwani et al., 2010). Saccade duration is the total time taken to make a saccade, which is recognised as one of the indexes to assess operator's workload. Saccade velocity is how fast the eyes move between fixations, which are associated with rapid deployment of attention. Therefore, saccades can be an effective indicator of situation awareness (Rognin et al., 2004; Gartenberg et al, 2014). ATCO's are constantly scanning the progress of aircraft in their sector in order to provide a safe and expeditious service. Observing ATCOs' eye movement patterns reveals that pupil dilation after alert activation is significantly bigger than before alert activation. It may be a side-effect of startle induced by an annoying auditory stimulus. However, there is no significant interaction between alerting design and alerting phase on pupil dilation. To develop an effective ATM system, the HCI design must integrate two factors, auditory semantic factors which convey a stimulus of alert and specify the nature of the event; and visual representation factors which include salient colours, shape, texture, and flashing to direct the attention to the source of the event. Cognitive processing of aural and visual information involves stimulation, perception, recognition, memory and comprehension which all together facilitate effective decision-making. Air Traffic Controller's cognitive processes for monitoring, identifying and solving potential conflicts require internal cognitive resources and external representation of objects, artefacts and interface designs (Ltifi et al., 2015). There are significant differences between ATCO's fixations, fixation duration, saccade duration and saccade velocity depending on whether the ATM system presents an acoustic or semantic audio alert (table 3.4). The information-rich design of a semantic alert not only has significantly increased fixation numbers, but also increased fixation duration after an alert activates. Furthermore, it not only reduces the time to make a saccade, but it also speeds up the fixation shifts compared with a simple acoustic design. These findings of saccadic activity of eye movement can further explain our previous findings of why semantic designed alerts significantly reduce ATCO's response time to critical system alerts such as STCA, APW and MSAW (Kearney et al., 2016).

ATCOs tend to spend more time looking at interesting objects in the interface displays, as their fixations are roving over the critical visual stimuli on the screens. The length of fixation duration can reflect difficulty in extracting information, and the number of fixations indicates the importance of the areas of interest (Kotval & Goldberg, 1998). Also, the phenomenon of tunnelled attention can be observed by the concurrence of an excessively long fixation duration dwelling on a specific area, reduced saccades, and decreased scanning frequency on the interfaces (Kowler, 2011). According to cognitive fit theory (Vessey, 1991), the most important factor in improving ATCO's task performance is designing the semantic aural alert integrating visual representation which corresponds to the mental model of the ATCO. The initial auditory BEEP on semantic alert attracts air traffic controllers' attention following by specific the nature of the alert i.e. Conflict, Airspace or Altitude. The ATCO will not be startled by the activation of the audio warning and no further cognitive load in evaluating the forthcoming threats is required. ATCO can immediately begin to develop conflict resolution strategies. Therefore, semantic design provides crucial extra time to support ATCO real-time decision-making to deploy the most appropriate response to specific critical event.

3.6 Summary

Under high demand of monitoring, planning and controlling large numbers of aircraft, ATCOs not only have to communicate with pilots, but also have to deal with unexpected situations to maintain safe, orderly and expeditious flows of air traffic. The natural limitations of human cognitive processes and the vast number of parallel monitoring tasks are the reason for providing decision support tools in an ATM system, especially as air traffic continues to increase. HCI design should be able to provide an effective alert which facilitates the ATCO's attention being alerted without startle and directed to the conflict being presented with coincident knowledge to support ATCO's decision-making to solve the conflict. The semantic alert demonstrated good matching between external events and ATCO's internal resources by facilitating cognitive processes to integrate auditory stimuli and directing visual attention, hence promoting effective ATCO's decision-making and speeding up ATCO response time to STCA. Automated aids are designed to improve ATCO's performance with more timely perception and precise comprehension of visual and auditory information. The findings could be applied to improve the alerting design of the COOPANS Air Traffic Management system, and in developing controllers' training syllabi to increase ATCO's situation awareness.

The design of decision support systems for use in dynamic environments must efficiently integrate with the characteristics of human cognitive processing. It is necessary to provide air traffic controllers with context-specified semantic stimuli which are appropriately salient and which provide specific information to reflect the nature of critical situations in order to minimise the side-effect of startle. The results of this research demonstrate that semantic alerts provide not only level-1 SA, detecting the conflict by increasing fixation numbers and fixation duration to STCA, but also promote level-2 SA in assisting ATCOs understanding of the nature of critical events denoted by quick saccade duration and saccade velocity developing quicker strategies for conflict resolution. Consequently, the design of a semantic alert can significantly reduce ATCOs' response time, therefore providing valuable extra time in a time-limited situation, to formulate and execute resolution strategies. The findings of this research indicate that the context-specified design of semantic alerts could improve ATCO's situational awareness and significantly reduce response time to perform conflict resolution. Resolving critical situations more effectively means that ATCOs can resume normal operations within the rest of the sector sooner minimising the overall impact to other aircraft and the air traffic system generally. Civil

Aviation Authorities, Air Navigation Service Providers and Air Traffic Management System Providers could all benefit from the findings of this research with a view to ensuring that Air Traffic Controllers are provided with the optimal context-specified alerting schemes to increase their situational awareness to handle unforeseen critical events.

CHAPTER IV

Visual Scan Patterns of Single Air Traffic Controller Performing Multiple Remote Tower Operations

4.1 Introduction

The initial concept of remote tower operation (RTO) was for air traffic services (ATS) to be delivered remotely without direct observation from a local tower (Kraiss & Kuhlen, 1996). Based on the concept of remote tower operations, multiple remote tower operations (MRTO) offers further opportunity for cost efficiency of air traffic services for small and medium sized airports, especially if a single controller could provide air traffic services to two (or more airports) at the same time. Remote tower technology allows one air traffic controller (ATCO) to control one or more airports at the same time, a significant consideration of course are the appropriate traffic volumes for a single air traffic controller to manage (SESAR Joint Undertaking, 2013, 2015). ATCOs use Out the Window (OTW) visualisation media supported by radar data processing (RDP), electronic flight strips (EFS) and a voice communications network (VCS) to provide air traffic services (Moehlenbrink & Papenfuss, 2011). This Multiple Remote Towers research project was sponsored by the Single European Sky ATM Research Program (SESAR) and the ATM Operations Division of the Irish Aviation Authority. The Remote Tower Centre (RTC) was located at Dublin Air Traffic Services Unit, 150 miles away from both Shannon and Cork airports where the services were provided simultaneously. Cork airport handled approximately 50,242 movements in 2016 and Shannon airport handled approximately 25,059 movements in 2016 (Irish Aviation Authority, 2017).

The innovative concept of Multiple Remote Tower Operations (MRTO) is principally suitable for lower traffic density airports. The visual cues and objects which ATCOs routinely use for safe operations must be provided by the surveillance cameras; the data-communication links and the systems must support the provision of air traffic services at two (or more) different airfields simultaneously (Van Schaik et al., 2016). Ground-breaking technology enables precise image-video resolution for signal detection and recognition. The crucial factor to assure aviation safety is the cooperative interaction between the human and the technical systems being used (Onken & Walsdorf, 2001). ATCO's visual attention and situation awareness are the main safety concerns of human-computer interaction in MRTO, as the expectation of MRTO is for 'a single ATCO to perform the tasks originally designed to be executed by up to four ATCOs'. Therefore, the development of enhanced video resolution for remote air traffic services is not sufficient, it must integrate human-centered design in MRTO systems (Friedrich & Mohlenbrink, 2013; Kearney, Li, Braithwaite, & Greaves, 2017).

4.2 Objectives of Single European Sky ATM Operational Steps

The EU Single European Sky initiative (SES) was introduced to restructure European airspace and propose innovative measures for air traffic management to achieve the objectives of enhanced cost-efficiency and improved airspace and airport capacity whilst simultaneously improving safety performance. The main driver of the implementation of the remote tower concept is cost-efficiency and the safety criteria to be applied should ensure that the level of safety after the introduction into service of the remote tower concept is at least not reduced compared to current conventional tower operations (European Aviation Safety Agency, 2015a). Many air navigation service providers (ANSPs) have developed automated systems using video-panorama cameras for synthetic outside views (Leitner & Oehme, 2016). Research into remote tower operations increased over the last 20 years (European Aviation Safety Agency, 2014; SESAR Joint Undertaking, 2015). The emerging technology of RTO developed slowly during the initial stages but in recent times has taken a leap forward with virtual tower operations based on EUROCAE WG-100 standard "Remote and Virtual Towers" (EUROCAE, 2016). Research on multiple remote tower operations directly contributes to the objectives of the simultaneous provision of remote Air Traffic Services for multiple aerodromes. It is outlined in the Operational Improvement Step (OIS) SDM-0205 linked to SESAR Work Package (WP) 06.09.03 of the EU ATM Master Plan. This activity falls under SESAR Operational Step 3 for multiple remote tower operations (figure 4.1).

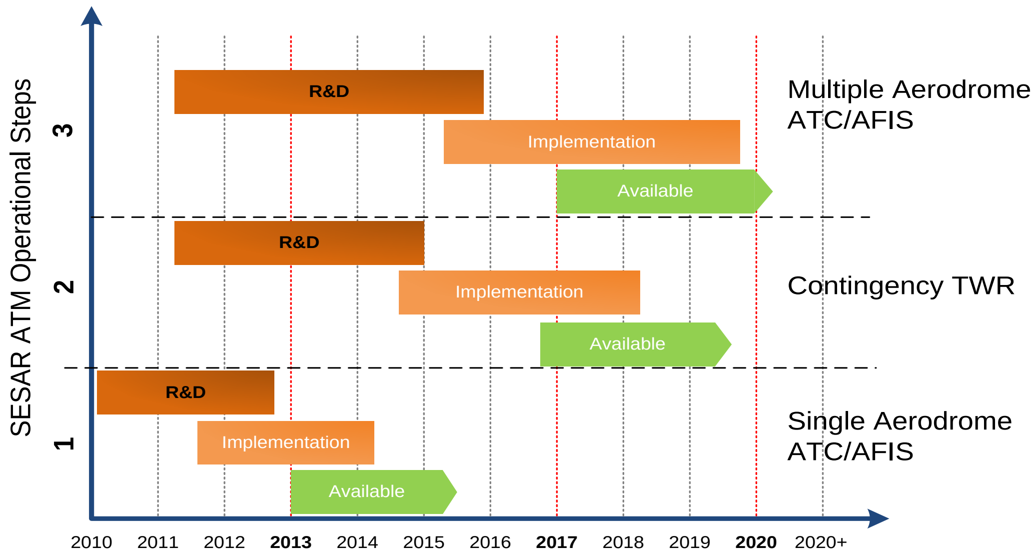

Figure 4.1. The Timelines of SESAR ATM Operational Steps for Single Aerodrome, Contingency Tower and Multiple Aerodrome ATC/AFIS

4.2.1 The Development of Multiple Remote Tower Operations

Innovative systems development requires careful assessment of human information processing at the initial design stage to assure effective operators' situation awareness, safety and cost-efficiency (Chang, Yang, & Hsiao, 2016; Honn et al., 2016). The cognitive match between an ATCO's information processing and external information presentation is a key requirement for effective monitoring performance in multiple remote tower operations. A well-designed interface should provide sufficient cues to rapidly direct the operator's visual scanning to desired objects with the least fixation duration. Therefore, highlighting the importance of the design of controller's working position (CWP) for presenting information via Out the Window visualisation (OTW), Radar Data Processing (RDP), Electronic Flight Strips (EFS) and a Communications Network (VCS) to provide air traffic services, which is an emergent theme of HCI on MRTO (Hollan, Hutchins, & Kirsh, 2000).

The US NextGen program (Federal Aviation Administration, 2012) also investigates the diverse aspects of tower control including human-computer interaction, situation awareness, cost of airport control tower, safety management and capacity variation. Similarly, NASA has examined remote tower operations for improving runway safety (Dorighi & Rabin, 2002). Preliminary research found that RTO can provide substantial economic benefits compared with traditional operations of local physical air traffic control towers, as NextGen proposed an innovative concept to address airport capacity problems by introducing more integrated tower information, providing weather conditions and surveillance data as well as decision support tools to ATCOs (Nene, 2008). The results of human-in-the-loop experiments demonstrated that the concept of remote tower operations exhibited encouraging improvements in communications and departure rates with no differences in perceived workload, effort, safety and situation awareness (Nickelson, Jones, & Zimmerman, 2011). Learnings from multiple remote tower operations are not only beneficial in understanding the performance of innovative systems but will also assist in how these advanced systems can impact on safety, capacity and cost-efficiency (Irish Aviation Authority, 2016; Van Lancker et al., 2016).

4.2.2 Interface Design Impact to ATCOs' Cognitive Processes

Working with advanced automated systems, human operators not only have to monitor multiple displays with efficient distributed attention, but they must also intervene if automation fails by relocating their attention to the area requiring immediate attention (Carmen Bruder, 2014). The path of visual attention can reveal the cognitive process of human-computer interaction between operators and machines (Allsop & Gray, 2014; Kearney, Li, & Lin, 2016). Therefore, an operator's eye movements on the displays can reveal human information processes and how the interface design impacts operator's performance (Goldberg & Kotval, 1999). For example, saccades (rapid movements between fixations) may reflect the operator's direction of an attention shift (Katoh, 1997; Kowler, 2011; Salvucci & Goldberg, 2000), the distribution of one's fixations on an interesting area is related to attention allocation (Henderson, 2003), and can facilitate mechanisms to construct situation awareness (Johnson & Proctor, 2004). In this way, an ATCO's eye movement parameters can be treated as a window into the cognitive system, allowing interface designers to capture ATCO's cognitive process (Henderson, 2003). Pupil dilation increases as a function of cognitive demand. ATCO's are constantly scanning the progress of aircraft in order to provide a safe separation and expeditious service. Observing ATCOs' eye movement patterns reveals that pupil dilation after alert activation is significantly bigger than before alert activation (Kearney, Li, & Lin, 2016).

Visual attention is a precursor to initiating the cognitive process involved in attention distribution, situation awareness, and real-time decision-making (Lavine et al., 2002). Since the air traffic management system in Europe often operates to its limits, new operational concepts and technologies are constantly required to enhance capacity, safety and cost-efficiency. Future ATM systems must increase capacity and improve safety standards while at the same time deliver economic improvements (Muller, Giesa, & Anders, 2001). The duration of human visual scanning is more related to processing complexity than to visual search efficiency (Robinski & Stein, 2013), as much more time is spent in fixations than in saccades. A saccade amplitude is computed from the sum of the distances between consecutive fixations with the units of pixels or visual angle degree between each successive fixation (Goldberg & Kotval, 1999). That means the more saccade amplitude deployed in visual scans on an specific display, the more attentions distributed to the instrument related to task performance (Katoh, 1997). On the other hand, saccade amplitude could be an index to observe if the interface design increases operator's cognitive process or not (Liversedge & Findlay, 2000). In addition, effective saccades play an important role in scanning the elements, which could in turn be used to identify whether the elements being scanned are relevant or irrelevant based on the saccade velocity (McColemana & Blair, 2013; Remington, Wu, & Pashler, 2011). It appears that saccade velocity might be associated with how fast the operator's attention shifts and cognitive process (K. Rayner, 1998).

4.2.3 Visual Parameters Related to Human-Computer Interaction

The path of fixations is associated with selective attention and accurate judgments for perceptual targets (Henderson, 2003). Saccadic eye movements are controlled by top-down visual processes, which are coordinated closely with perceptual attention (Zhao et al., 2012). This indicated saccadic paths are intentional and based on the requirements of the task and trajectory prediction to the near future (Kowler, 2011). However, Wickens et al. (2001) proposed that attention allocation is determined by the bottom-up capture of salient stimulus, inhibited by the effort required to move the focus of attention, and driven by the expectancy of seeing valuable stimulus in the traffic environment. To apply eye tracking technology in the context of monitoring tasks, it is necessary to understand the pattern of ATCO's monitoring is reflected by eye movements, such as how ATCOs guide their eye movements during monitoring phases and how eye scan patterns change during the monitoring process (Hasse & Bruder, 2015). Most eye movements are in the form of saccades and fixations which are fast eye movements followed by a period of remaining relatively stationary in the same position. The features of slower saccade velocity over the relevant areas of interests (AOIs) could be associated closely with the knowledge-based visual scan process (Hoffman & Subramaniam, 1995). AOIs were defined as ATCO's fixations gathered together closely on a specific display which suggests there is some information in the closeness of these fixations that attracts ATCO's attentions. Saccadic eye movements are proven as top-down visual processes relating to ATCO's perceptual attention (Zhao et al., 2012).

ATCOs not only have to distribute their attention to detect potential conflicts among aircraft, both in the air and on the ground, but also have to monitor several radio frequencies to maintain situation awareness to prevent critical events. Condensed monitoring tasks and an augmented visual channel is foreseen as the most promising way to increase the capacity and safety of air traffic services (Beier & Gemperlein, 2004). Visual parameters are related to different operational content (Yu et al., 2016), which could explore the interaction between human operator and the innovative technology of remote tower (Koenig & Lachnit, 2011; Komogortsev & Karpov, 2013). Monitoring performance is the most critical aspect related to safety in multiple remote tower operations. By applying eye tracking technology, ATCOs' eye movements and attention distributions can be investigated either bottom-up (stimulus-driven) or top-down (goal-driven) cognitive processes, the nature of the monitoring task will feed back to system design and ATCOs' training in the future. The eye tracking parameters are well suited for calculating the outcome of monitoring tasks (Hasse, Grasshoff & Bruder, 2012). Based on literature reviews, there are four null hypotheses regarding ATCOs' visual parameters on performing MRTO which will be tested as follows,

H_0: ATCOs' fixation counts on the AOIs would have no significant interaction effect to perform MRTO tasks

H_0: ATCOs' fixation duration on the AOIs would have no significant interaction effect to perform MRTO tasks

H_0: ATCOs' saccade amplitude on the AOIs would have no significant interaction effect to perform MRTO tasks

H_0: ATCOs' pupil dilation on the AOIs would have no significant interaction effect to perform MRTO tasks

4.3 Method

4.3.1 Scenarios

The SESAR Safety Case for certification of multiple remote tower operations has distinct safety requirements for live trials. This approach outlines the activities of safety assessment to be conducted for the entire Multiple Remote Tower Systems including people, procedures, and equipment. Thirty-two scenarios were recorded using an eye tracking device to investigate human-computer interaction and use of the supporting camera systems of a single ATCO performing live exercises of multiple remote tower operations. The recordings consisted of tracking ATCOs' visual parameters across display systems while performing real and realistic multiple remote tower operations.

All scenarios contained three different air traffic control tasks: surface movement control (SMC), which is the air traffic control service provided to aircraft, vehicles and personnel on the manoeuvring area of an aerodrome excluding the runway in use at both Shannon and Cork airports; air movement control (AMC) which is the air traffic control service provided to aircraft in the vicinity of an aerodrome and to aircraft, vehicles and personnel on the runway in use in at both Shannon and Cork airports; and SMC plus AMC involving both

Shannon and Cork airport. The approval of the Cranfield University Research Ethic Committee was granted (CURES/1506/2016) in advance of the research taking place. All collected data were only available to the research team and stored in accordance to the United Kingdom Ethical Code and the Data Protection Act.

4.3.2 Apparatus

Remote Tower Module (RTM): The RTM accommodates SMC and AMC working positions equipped with identical display systems including (1) the out of the window (OTW) visualisation with fourteen active screens and one standby unit in the event of equipment failure. The displays match the Pan Tilt Zoom (PTZ) Camera resolution of 1920 x 1080 pixels with a refresh rate of 60Hz in a 220 degrees configuration. These screens are sufficiently flexible to permit an ATCO to arrange the airports view to be split evenly between the two airports or if the operational situation requires, to have a larger view of a particular airport; (2) electronic flight strip (EFS) system which is divided into two parts; one for Shannon airport and one for Cork airport; (3) radar data processing (RDP) which can be used as a distance indicator to touch-down and is divided into two parts one for Shannon and one for Cork airport; (4) a voice communication system (VCS) which was equipped with a Schmid Communications Panel. It is used for both GND-AIR and GND-GND communications comprising all necessary frequencies and intercom direct dial buttons. These four displays on RTM are the areas of interest (AOIs) for human-computer interaction analysis in multiple remote tower operations. These four AOIs are the main sources of information related to ATCO’s task performance. To increase ATCO’s situation awareness, the borders of the display systems of OTW, RDP and EFS were distinguished by colours, Purple indicated Shannon airport, Green indicated Cork airport. The RTM is configured with the appropriate Shannon AMC/SMC and Cork AMC/SMC ATC VHF frequencies, the frequencies of Shannon on the top and the frequencies of Cork on the bottom. They are also colour coded to provide additional situation awareness to ATCOs (Purple for Shannon and Green for Cork, see figure 4.2).

Eye Tracking Device: A wearable and light-weight eye-tracking device “Pupil Pro” which consists of a headset including two cameras for eye movement data collection and analysis (Figure 2). The headset hosts two cameras, one facing the right eye of the participant (eye-camera) which has a resolution of 800 x 600 pixels and a frame rate of 60 Hz, the other camera capturing the field of vision (world-camera) which has frame rate of 60 Hz. These two cameras can be synchronised after calibration. The ‘world-camera’ is mounted on the right top of the headset showing the orientation and view of the ATCO’s view of the area of interests; the eye-camera is mounted offset right and low and is adjustable to suit different wearer’s facial layout and track their pupil parameters accordingly (Kassner, Patera, & Bulling, 2014).

Figure 4.2. ATCO’s Using Pupil Pro Eye Tracker interacted with RTM comprised OTW, RDP, EFS and VCS for Multiple Remote Tower Operations.

4.3.3 Research Design

Thirty-two live exercises providing ATS for both Shannon and Cork airports from the remote tower control centre located at Dublin airport were conducted. The participants were all qualified ATCOs, holding operational licences for both Shannon and Cork airports. The assessment of human-computer interactions is based on ATCO's visual attention among AOIs while performing SMC and AMC tasks. Therefore, these 32 scenarios comprised three types of operation as between-subject variables, (1) SMC on both Shannon and Cork airports simultaneous; (2) AMC on both Shannon and Cork airports simultaneous; (3) AMC plus SMC on both Shannon and Cork airports simultaneous. The definition of 'simultaneous' is where the spacing between two aircraft arriving or departing at Shannon and Cork airports is less than that required if the two aircraft were landing or departing at the same airport. It means that the activities of AMC, SMC and AMC plus SMC on both Shannon airport and Cork airport are simultaneously being monitored and controlled by a single ATCO.

The eye tracking device collected and analysed ATCOs' visual parameters including fixation count, fixation duration, saccade amplitude and pupil dilation across the different interface displays (OTW, EFS, RDP & VCS) on the RTM. The definition of fixation in this research is when the ATCO constantly maintains a gaze in a direction over 100 milliseconds. Due to different time frames for completing each scenario, all of 32 scenarios of eye tracker data are analysed for chunks of 60 seconds. The time frames of recorded eye movements contain the most critical visual parameters which reflect ATCO's cognitive processes and visual attention shifting among OTW, EFS, RDP and VCS. The research questions to be investigated by eye tracking data are:

1. Will scanning be influenced in relation to task demands of MRTO?
2. Will the ATCO's visual parameters vary while interacting with interfaces?

3. Are the interfaces on CWP providing the necessary information to the ATCO for MRTO?

A period of 60 seconds for analysing ATCO's visual attention was supported by the consensus of experienced controllers. The live trial exercises related to remote control of over 500 live dynamic aircraft activities between Shannon and Cork airports. A project team was established to ensure that all aspects of relevant aviation activity were represented in the project. The project team consisted of a Project Manager, an ATM Specialist, a Human Factors Expert and two appropriately rated Controllers who were present for the live trials. To assure the safety of operations during the provision of service from the remote tower centre, both local towers were fully manned and operating in so-called shadow mode, capable of intervening in operations as required.

4.4 Results

The core concept of MRTO is to improve cost-efficiency and capacity of air traffic service and maintain or improve the level of safety. The Air Navigation Service Provider and the Safety regulator's concerns on safety and human performance in respect of ATCO's attention distributions and operational performance had to be investigated before implementation. The complexity of MRTO involves organising the traffic flow, providing information, and maintaining separation rules to both aircraft and ground vehicles between Shannon and Cork airports for SMC and AMC by interacting with OTW, EFS, RDP and VCS on monitoring tasks. The safety back-up of shadow operations from the physical towers at both Shannon and Cork airports never needed to intervene in the work of the single ATCO during the live demonstrations of multiple remote tower operations. When dealing with safety critical work contexts, the most suitable approach for cognitive processes assessment relies on unobtrusive techniques (Marchitto et al., 2016). This is the reason for applying eye tracking technology in this research. The results demonstrated that there are some substantial differences on ATCOs' visual parameters on different AOIs while performing AMS and SMC by remote tower module.

4.4.1 Sample Characteristics

Thirty-two scenarios of multiple remote tower operations included 11 SMC, 11 AMC and 10 SMC plus AMC were recorded by using an eye tracking device. ATCOs' eye movements across the displays on CWP including RDP, EFS, VCS and OTW were analysed while performing SMC, AMC and SMC plus AMC at both Shannon and Cork airports. A series of mixed ANOVAs with AOIs (four levels: RDP, EFS, VCS, and OTW) as within-subject factor and operational tasks (three levels: SMC, AMC, and SMC+AMC) as between-subject factor were performed to assess single ATCO's eye movement patterns on human-computer interactions in multiple remote tower operations. The response variables are fixation count (FC), fixation duration (FD), saccade amplitude (SA), and pupil size (PS). The assumption of sphericity was verified by using Mauchly's test, and the Bonferroni was applied to perform pairwise comparisons after a significant overall test. Effect size of factors and interactions were quantified by partial eta square (η_p^2). The descriptive statistics of sample characteristics were shown in table 4.1.

Table 4.1. Descriptive statistics of mean and standard deviation of four eye movement parameters among three tasks and four AOIs

Tasks	Visual Parameter	N	RDP	EFS	VCS	OTW
SMC	FC	11	19.18(11.7)	17.09(14.08)	3.36(3.91)	64.91(18.31)
	FD	11	.239(.079)	.247(.105)	.200(.202)	.307(.084)
	SA	11	70.35(26.58)	66.57(42.09)	49.60(46.34)	113.45(28.7)
	PS	7	76.22(3.41)	69.81(9.12)	81.01(6.04)	75.99(3.74)
AMC	FC	11	32.27(10.49)	43.36(25.2)	12.00(14.33)	38.82(14.85)
	FD	11	.263(.041)	.262(.060)	.156(.137)	.258(.038)
	SA	11	43.07(18.96)	43.94(20.53)	15.85(19.15)	137.57(28.9)
	PS	7	84.91(4.65)	83.70(10.41)	94.64(22.09)	85.86(10.83)
SMC+ AMC	FC	10	23.50(16.64)	56.80(39.28)	2.20(3.82)	26.40(19.95)
	FD	10	.339(.182)	.238(.104)	.154(.266)	.303(.104)
	SA	10	52.60(25.17)	36.00(34.01)	20.81(41.54)	141.00(38.4)
	PS	3	79.54(9.24)	77.82(10.58)	87.42(21.80)	77.84(11.28)

4.4.2 Fixation Counts (FC) among Interface Displays

There is a significant interaction between different interfaces (AOIs) and tasks, F (3.20, 46.40) = 7.496, p < .001, η^2 =.341. A significant main effect of AOIs, F (1.60, 46.401) = 23.205, p < .001, η^2 =.445 was found, but main effect of tasks is insignificant, F (2, 29) = 2.426, p = .106, η^2 =.143. Post-hoc comparison on AOI revealed that fixation counts on the communication system (FC_{VCS}) are less significant than on the radar data (FC_{RDP}), the strips (FC_{EFS}), and the outside view (FC_{OTW}), p < .001. Moreover, FC_{RDP} is smaller than FC_{EFS} (p < .05) and FC_{OTW} (p < .001). Post-hoc comparison revealed FC_{SMC} is smaller than FC_{AMC} (p < .05) (figure 4.3). The results demonstrated that ATCOs exhibited the highest fixations numbers (64.9) at OTW and the lowest fixation numbers at VCS on SMC; however, EFS has the highest fixation numbers in both AMC (43.4) and AMC plus SMC (56.8). The SMC operation results in the highest usage of the outside camera view as indicated by the high fixations counts. The AMC operation scores high on flight strips and the outside camera (table 4.1). Combining the two increases the usage of the strips to the highest levels, while the ATCO interaction with the camera system is decreased to the lowest levels. The controller is adapting task strategies to the situation and enhances their preparation by using flight strips data intensively while performing AMS plus SMC. Therefore, the first null hypothesis ‘H_0: ATCOs’ fixation counts on the AOIs would have no significant interaction effect to perform MRTO tasks’ is rejected.

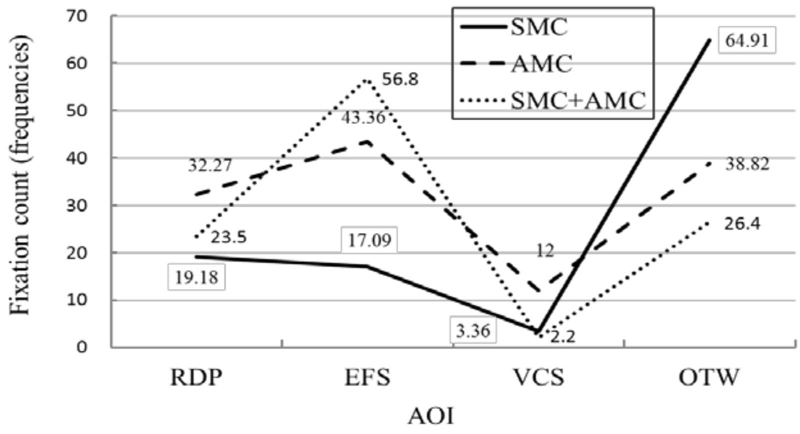

Figure 4.3. The differences of fixation count among AOIs and distinctive patterns of three tasks

4.4.3 Fixation Duration (FD) among Interface Displays

There is no significant interaction between different interfaces (AOIs) and tasks, F (3.702, 53.680) = .705, $p > .05$, $\eta^2 = .046$. A significant main effect of AOIs was found, F (1.851, 53.680) = 5.070, $p < .05$, $\eta^2 = .149$, but no significant main effect on tasks, F (2, 29) = .406, $p = .670$, $\eta^2 = .027$. Post-hoc comparison on AOIs revealed FDVCS is smaller than FDRDP ($p < .05$) and FDOTW ($p < .01$) (figure 4.4). Fixation duration has a significant main effect on AOIs and revealed that ATCOs distributed the longest fixation duration on the RDP on both AMC (263 ms) and SMC plus AMC (339 ms). However, the longest fixation duration of SMC is on OTW (307 ms). Again, the shortest fixation duration is on VCS across three tasks (table 4.1 & figure 4.4). The item of interest is held approximately stable on the retina during fixations with the majority between 154 ms and 339 ms depending on the complexity of information being processed and current cognitive load of ATCOs (table 4.1). Task and strategy related trends can be observed. Fixation duration is the lowest on the communication device. Combining SMC and AMC (high task load situation) results in longer fixation duration on radar data and similar levels for the using the cameras as during

SMC. The effects are relatively small as fixations duration are bound by a minimum and in fact has no significant interaction between AOIs and tasks. Therefore, the second null hypothesis ‘H_0: ATCOs’ fixation duration on the AOIs would have no significant interaction effect to perform MRTO tasks’ is accepted.

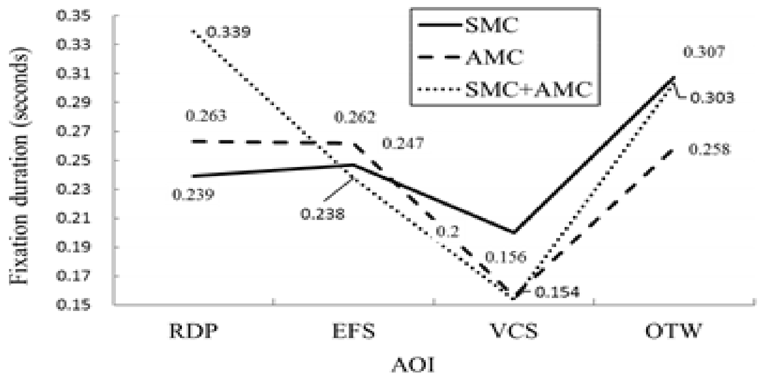

Figure 4.4. The differences of fixation duration among AOIs and three tasks

4.4.4 Saccade Amplitude (SA) among Interface Displays

There is a significant interaction between different interfaces (AOIs) and tasks, $F(6, 87) = 2.437$, $p < .05$, $\eta^2 = .144$. A significant main effect of AOIs, $F(3, 87) = 57.752$, $p < .001$, $\eta^2 = .666$ was found. A significant effect of tasks, $F(2, 29) = 3.578$, $p < .05$, $\eta^2 = .198$ was found as well. Post-hoc comparison on scenarios revealed participants’ SASMC is higher than SAAMC ($p < .05$). Post-hoc comparison on AOIs revealed SAVCS is smaller than SARDP ($p < .01$), SAEFS ($p < .05$), and SAOTW ($p < .001$). Moreover, SARDP and SAEFS are smaller than SAOTW ($p < .001$) (figure 4.5). The VCS is the smallest saccade amplitude consistent with SMC (49.6 degree), AMC (15.85 degree) and SMC plus AMC (20.81 degree) (table 4.1) compared with EFS, OTW and RDP. The VCS is the smallest saccade amplitude consistent with SMC (49.6 degree), AMC (15.85 degree) and SMC plus AMC (20.81 degree) compared with EFS, OTW and RDP. However, the OTW is the highest saccade amplitude across SMC (113.45 degree), AMC (137.57 degree) and SMC plus AMC

(141 degree) (table 4.1& figure 4.5). It revealed that OTW comprised of 14 visual reproduction display screens is a good human-centered design to facilitate ATCOs searching required information to perform MRTO. Therefore, the third null hypothesis is 'H_0: ATCOs' saccade amplitude on the AOIs would have no significant interaction effect to perform MRTO task' is rejected.

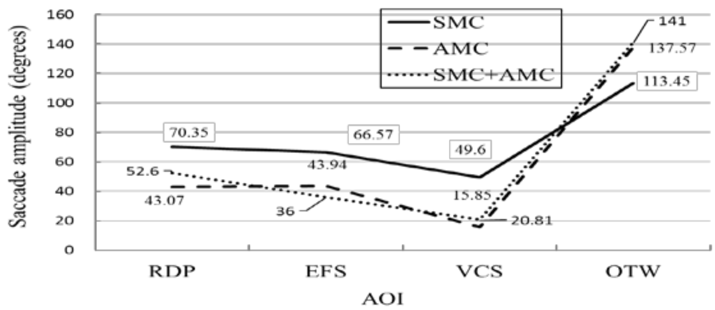

Figure 4.5. The differences of saccade amplitude among AOIs and distinctive patterns of three tasks

4.4.5 Pupil Size (PS) among Interface Displays

Results indicated the interaction between different interfaces (AOIs) and tasks is not significant, $F(3.05, 21.35) = .307$, $p > .05$, $\eta^2 = .042$. A significant main effect of AOIs, $F(1.53, 21.35) = 5.790$, $p < .001$, $\eta^2 = .293$ was found, but no significant main effect on tasks, $F(2, 14) = 2.765$, $p = .097$, $\eta^2 = .283$. Post-hoc comparison on AOIs revealed participants' PSVCS is higher than PSEFS ($p < .01$) and PSOTW ($p < .01$). The results revealed that ATCO's pupil dilation has significant main effect on AOI (table 4.1 & figure 4.6). The VCS is the highest pupil dilation consistent with AMC (94.64 pixels), SMC plus AMC (87.42 pixels) and SMC (81.01 pixels) compared with EFS, OTW and RDP. On the other hand, the EFS is the lowest pupil dilation across AMC (83.7 pixels), SMC plus AMC (77.82 pixels) and SMC (69.81 pixels). Therefore, the fourth null hypothesis is 'H_0: ATCOs' pupil dilation on the AOIs would have no significant interaction effect to perform MRTO tasks' is accepted.

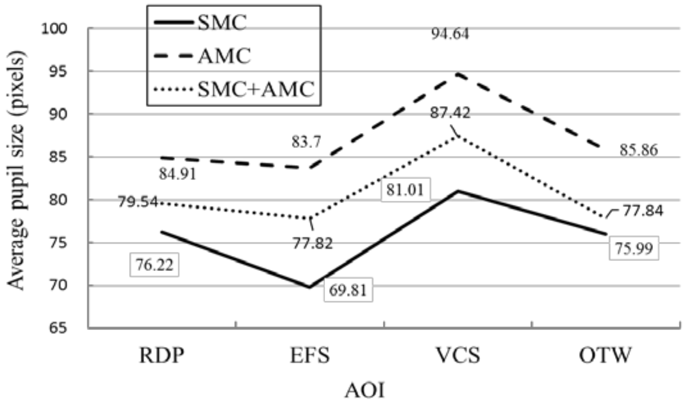

Figure 4.6. The differences of pupil size among AOIs and distinctive patterns of three tasks

4.5 Discussion

These live demonstrations of multiple remote tower operations represented all aspects of AMC and SMC including vehicle manoeuvres and aircraft arriving and departing from Shannon and Cork airports. The result of this research has demonstrated that a single ATCO with the assistance of advanced technology is able to perform multiple remote tower tasks without compromising operational safety. Furthermore, ATCOs' eye movement parameters (fixation counts, fixation durations, saccade amplitude & pupil dilation) can be measured in live operations and showed significant interactions effects between performing tasks (AMC, SMC or AMC plus SMC) and interfaces (EFS, OTW, RDP & VCS) on CWP whilst conducting monitoring tasks for multiple remote tower operations. This research reflected that design of innovative air traffic management systems involving human-computer interactions requires an understanding of ATCO's cognitive processes and the operational deployment context in order that safety and capacity are not only maintained but enhanced

(Langan-Fox, Canty & Sankey, 2009). Previous visual science research found that increased challenge levels in tasks could influence operators' visual parameters such as increasing the frequency of long fixations (Van Orden et al., 2001). The results of this research can provide a basis for future training and design for multiple remote tower operations.

4.5.1 ATCO's Visual Scan Patterns Related to Tasks Demanding

The design of visual presentation on interface displays is the substantial factor to be considered from human-computer interactions and safety perspective for multiple remote tower operations. ATCOs tend to spend more time looking at interesting objects in the interface displays, as their fixations are drifting over the critical visual stimuli on the screens for tasks performance. The length of fixation duration can reflect difficulty in extracting information, and the number of fixations indicates the importance of the areas of interest (Kotval & Goldberg, 1998). RTM provides detailed information which enables ATCOs to maintain continuous observation of all flight operations by using visual reproduction display screens (European Aviation Safety Agency, 2014, 2015b). It is an interesting finding and demonstrates that ATCOs distributed their fixations and shifted their attention in order to maintain situation awareness between two different airports based on the priority of the dynamic tasks (figure 4.7). Given that multiple remote tower is an innovative technology in the field of air traffic management, corresponding interface design should be evaluated so that ATCOs' workload could be minimised (Goldberg & Kotval, 1999). The analysis of eye movement data found that ATCOs' scanning patterns were influenced by the performing tasks (SMC, AMC or SMC plus AMC). Multiple remote tower operations at two airports is achieved through the support of advanced technology, however increased visual monitoring tasks might induce perceived workload as a potential cost based on visual parameters. This is the reason both EFS and OTW have high percentages of fixation counts in these three different tasks, 79.2% at SMC, 65.3% at AMC and 77.4% at SMC plus AMC. SMC is focused on the ground movements of vehicles and aircraft, ATCOs relied heavily upon OTW by using PTZ to track the positions of aircraft and vehicles, therefore, the highest frequency of fixation (64.9) is on the SMC for both airports. VCS showed the lowest fixation counts across three tasks, as there is no ongoing operational requirement to switch the frequency of voice communication system once the appropriate frequencies are initially selected.

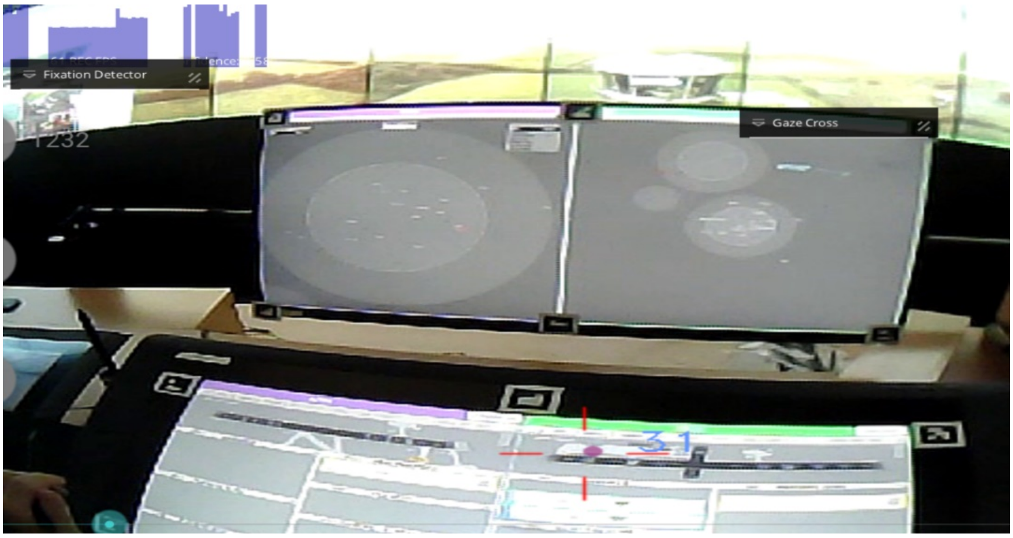

Figure 4.7. ATCO shifting attention from Shannon to Cork airport to pay attention on the runway activities on the EFS (fixation shown as red-cross recorded by eye tracker)

4.5.2 Visual Behaviours Reflecting Complexity of Multiple Tasks

Fixation numbers and fixation duration are closely linked to each other and are related to cognitive process and human performance (Yu et al., 2016). Short fixation durations primarily indicate operators encoding an element into working memory, and a longer fixation is more likely to signal deeper processing (Ballard et al., 1997). The results demonstrated that visual attention relating to human performance when performing multiple remote tower operations did not exceed the 1,000 millisecond of end-to-end delay, and fitted the requirements of safety assessment (European Aviation Safety Agency, 2015a). To ensure the safety of operations while a single ATCO performing multiple remote tower operations at two different airports and whilst fulfilling the roles of SMC and AMC at both airports, ATCOs found that it would be appropriate to add additional time and lateral spacing between aircraft cleared for take-off so that ATCOs can monitor the roll and initial rotation of the first aircraft before clearing and monitoring a second aircraft for take-off or landing. This finding is important for subsequent operational procedure design.

Eye movements are influenced by the interface design, as information presented by RDP becomes conceptually more difficult, fixation duration increases, and the frequency of regressions increases to process the distance of aircraft for safe separation. Regressions allow ATCOs to revisit previously fixated stimuli such as the text of aircraft call-sign, the figures of flight levels, or images of symbols on the interface displays, and physically returning the eyes to the location of the stimulus could cue the ATCO's memory for that stimulus, effectively aiding the comprehension process (Booth & Weger, 2013). There is a close connection between fixation duration and amount of information processing (Rayner, 1998; Singh & Singh, 2012). When an AMC is managing two simultaneous arrivals into two different airports, ideally the first landing aircraft should be stable on the runway before the second arrival aircraft is 1NM from touchdown at the other aerodrome. However, OTW is the longest fixation duration for SMC due to the nature of complexity of aircraft and vehicle movements in two airports simultaneously. A Single ATCO performing simultaneous AMC and SMC functions is the biggest challenge within MRTO, as RDP and OTW show long fixation durations on SMC plus AMC tasks. It requires further investigation to develop effective human-centered design to mitigate the potential risks on multiple monitoring and controlling tasks.

4.5.3 Human-Centered Design of CWP sufficiently Support Multi-tasks Performance

Visual activity is the objective method for assessing an ATCO's cognitive process related to real-time decision-making (Ayaz et al., 2010). The concurrence of excessive fixations, long fixation duration and less saccade duration is the precursor of tunnelled attention (Johnson & Proctor, 2004). ATCO's visual behaviours provide an opportunity to investigate the relationship between eye movement patterns and information processing. Eye scan pattern is one of the most powerful methods for assessing human beings' cognitive processes in Human–Computer Interaction. For example, saccade is defined as fast eye movement between fixations and generally it declines as a function of increased mental workload (Ahlstrom & Friedman-Berg, 2006). Saccade plays an important role in indicating workload imposed by different tasks among EFS, OTW, RDP and VCS. The results reveal that saccade amplitude has significant interaction between AOIs and tasks. ATCOs performing MRTO not only have to distribute their attention to detect potential conflicts among aircraft in the air and on the ground at both Shannon and Cork airports, but also have to resolve unexpected events under time pressure through radio telephony communications with pilots and others.

The VCS is the smallest saccade amplitude among EFS, OTW and RDP consistent with three different tasks. The VCS display consists of a screen with buttons and small digital numbers of radio frequencies used by all moving aircraft, vehicles and other parties on both Shannon airport (on the top of VCS) and Cork airports (on the bottom of VCS). ATCO's must pay attention to select the correct frequency, should an ATCO select an incorrect frequency they may miss transmissions from aircraft/vehicles and may not be able to transmit crucial information to aircraft/vehicles. It demonstrated that ATCOs have more mental workload while interacting with VCS for radio telephony communications compared with EFS, OTW and RDP. On the other hand, the OTW is the highest saccade amplitude across tasks. It can be explained that OTW is a good human-centered design to facilitate ATCOs searching required information to perform MRTO by selected ratio of screens to enlarge the images by PTZ. There are lots of Human-Computer Interactions related to the usages of PTZ, as the OTW screens are sufficiently flexible to permit an ATCO to have a larger view of a particular dynamic target to enhance situation awareness (figure 4.8).

Figure 4.8. ATCO using PTZ camera to enlarge the visual perception to enhance situation awareness during B-737 Landing

4.5.4 Integrated Visual Characteristics into Design Reduced Cognitive Loads

Eye tracking technology offers profound insights into human-computer interaction and the cognitive processes of ATCO's monitoring tasks. The measurement of pupil dilation has been used to investigate the status of cognitive processes and mental workload, as pupil diameter increases as an indication of cognitive demand (Ahlstrom & Friedman-Berg, 2006). VCS demonstrates the highest pupil dilation compared with EFS, OTW and RDP consistent with AMC, SMC plus AMC and SMC. It is evidence that VCS has induced significant cognitive loads to ATCO on monitoring tasks in selecting frequencies for communications, as ATCO's pupil dilation is the highest and the saccade amplitude is the smallest. This finding supports Ahlstrom and Friedman-Berg's (2006) proposal that 'saccade decreasing mental workload increasing, and pupil dilation increasing cognitive load also increasing'.

ATCOs must pay attention to select the correct air traffic control frequencies in order to provide effective ATS. Based on the eye tracking data analysis, there are two scenarios (6.25%) where an ATCO selected an incorrect frequency on the VCS then realised the errors and corrected them. This indicates a need to investigate how to deal with VCS design to enhance the safety of MRTO. On the other hand, the EFS is the lowest pupil dilation across AMC, SMC plus AMC and SMC. This finding implies that ATCOs had the lowest cognitive load while interacting with EFS compared with OTW, RDP and VCS. The different colour borders and runway layout on EFS are very good human-centered design, as it delineates different airports reducing ATCOs' cognitive load and facilitating task performance by clearly defined areas of aircraft information including Arrivals, Pending, Control Zone, Runway, Taxiway, Pushed and Cleared. The dotted-red border on the runway indicates the runway is occupied by a vehicle or aircraft, is used to enhance the ATCOs' situational awareness of activity on the runway and aid in preventing runway incursions. Furthermore, ATCOs are allowed to interact with EFS making notes to support working memory and to serve as reminders for secondary priorities of communication with pilots/vehicle drivers on both Shannon and Cork airports for the deferred responses due to performing multiple tasks (figure 4.9).

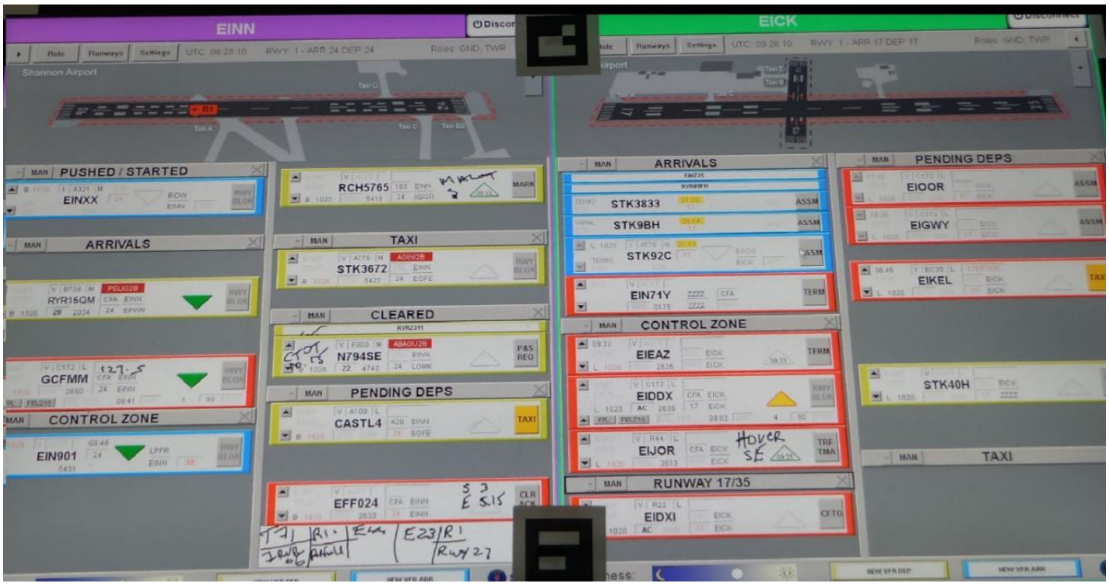

Figure 4.9. The differential design of colour on the border of EFS increasing ATCO's situation awareness (the Purple colour on the top left indicates Shannon airport, the Green colour on the top right indicates Cork airport)

4.6 Summary

ATCOs worked with innovative technology and display systems with outside views provided by PTZ camera whilst performing multiple remote tower operations. This research indicates that increased pupil dilation and decreased saccade amplitude in a visual search task are related to strategic adaption to the demands of the tasks for a single ATCO to perform MRTO. The distribution of visual attention among display systems is the key human-computer interaction issue in single ATCOs performing multiple monitoring tasks. Information presentation on the remote tower module and information interpretation by the ATCO are crucial elements in assuring aviation safety and optimal human performance. Current OTW and EFS on the RTM demonstrate that effective human-centred design in relation to information presentation can simplify ATCOs' cognitive processes by reducing the volume of visual searching thereby alleviating cognitive load. Furthermore, innovative remote tower technology will facilitate staffing and equipment cost-efficiencies including Communications, Navigation, Surveillance and Flight Data Processing Systems. There is potential to save approximately €2.21 million Euro per annum per installation. ATCO's visual attention and monitoring performance can be affected by how information is presented, the complexity of the information presented, and the operating environment in the remote tower centre. To achieve resource-efficient and sustainable air navigation services, there is a growing demand to improve the design of human-computer interactions in multiple remote tower technology deployment. These must align with high technology-readiness level, operators' practices, industrial developments, and the certification processes of regulators.

CHAPTER V

Human Performance Assessment of a Single Air Traffic Controller Conducting Multiple Remote Tower Operations

5.1 Introduction

The Initial development of remote tower operations commenced at the end of last century and was designed as a system to permit air traffic services (ATS) to be delivered remotely without direct observation from a local tower. The operational characteristics of remote tower operations differ profoundly from traditional physical tower operations. Digital Panorama-Cameras can be placed on the airfield providing ATCO's with real-time enhanced images through augmented visualisation functions from advanced technologies. The development of augmented visualisation technology has significantly changed the traditional air traffic management (ATM) system and air traffic controllers' (ATCO) task performance. Under continued pressure from economic regulators to improve ANSP cost-efficiency, the concept of single tower operations evolved to consider the possibility of multiple remote tower operations (MRTO) by applying video panorama-based remote tower working positions, which permit less controllers to fulfil the Air Traffic Management tasks at two or more airports (Kearney & Li, 2018). The Single European Sky initiative is expected to increase safety, capacity and reduce costs in order to meet the growing demand for aircraft operations in Europe. (Eurocontrol, 2014). An innovative strategy to achieve these objectives is multiple remote tower operations provided from a remote location from the airports under control. The application of panorama-video cameras enables air traffic controllers visually monitor aircraft approaching and departing from the airports under control by video-link from a remote tower centre (RTC). The Out of Window (OTW) function with pan-tilt-zoom (PTZ) cameras permits dynamic object detection, recognition, and identification, permitting the systems to meet the requirements and certification processes of regulators (Fürstenau, Mittendorf, & Friedrich, 2014). However, the advanced technology of MRTO also created some human performance safety concerns in relation to human-computer interaction (HCI) and mental workload, as MRTO expected one air traffic controller to complete the tasks originally managed by four ATCOs.

5.2 The Innovative Concept of Multiple Remote Tower Operation

Multiple Remote Tower Operations is also applicable to large airports, in some cases potentially as the primary tower and in others as a fully functioning contingency or backup system. Multiple remote tower operations will require changed procedures and standards from those prescribed in the International Civil Aviation Organisation Doc 4444 (Air Traffic Management) and EUROCONTROL's Manual for Aerodrome Flight Information Services (Eurocontrol, 2015). Differences between ATC provision from a RTC compared to traditional physical towers requires careful consideration and in-depth assessment to validate human performance capabilities as MRTO involves increased cognitive demands for a single ATCO performing several ATCOs' tasks (Hollan, Hutchins, & Kirsh, 2000; Li et al., 2018).

5.2.1 New Technology Induced New HCI Challenges

Air Traffic growth in recent years has highlighted deficiencies in infrastructure and airspace capacities resulting in increasing delays to aircraft and passengers. In response to this Single European Sky (SES) was established with the following objectives - improve safety, reduce the cost to airspace users, and lessen the environmental impacts (Eurocontrol, 2015). ATCOs' visual search whether on a radar display or an aerodrome control tower is critical for maintaining situation awareness, and their attention distributions can be significantly influenced by the surrounding environment, equipment eco-system and human machine interface design at the Controller Working Position (CWP). In order to achieve an understanding of the effects of different design on cognitive function, it is necessary to apply a holistic approach which includes a comprehensive assessment of human performance on MRTO (Lafond et al., 2009). The objectives of multiple remote tower operations are to bring capabilities to fit the SES high-level expectations, to enhance system contingency, to enhance ATCO situation awareness and maintain at least the same level of safety as per traditional towers (Eurocontrol, 2014). The HCI design of the CWP including Electric Flight Strips (EFS), Radar Data Processing (RDP), Voice Communication System (VCS) and Out of Window screens (OTW) impacts an ATCO's cognitive processes in terms of attention distribution, situation awareness and decision-making.

5.2.2 Augmented Vision Facilitate ATCO's Monitoring Performance

ATCOs have to constantly shift attention between outside views and ATM systems which generates workload and accumulates head-down time (Pinska, 2006). Both workload and head-down issues can be resolved by augmented vision design of OTW by superimposing traffic information and weather conditions on the airfield displays (Fürstenau & Schmidt, 2016; Schmidt, Rudolph, & Fürstenau, 2016). Human operator's situation awareness and task performance can be significantly improved and cognitive workload can be reduced by appropriate human-cantered design (Laois & Giannacourou, 1995; Tobaruela et al., 2014; Wickens & Hollands, 2000). However, inappropriate automation design can present many disadvantages and create potential system risks leading to accident/incidents, including loss of SA, and placing the human operators outside of the system control loop (Durso et al., 1998; Endsley, 1995). Augmented visualisation design is to enhance ATCO's situation awareness, using human information-processing models, ATCO's visual behaviours provide an opportunity to investigate the relationship between ATCO situation awareness and task performance (Kearney & Li, 2018). Eye scan pattern is one of the most powerful methods for assessing human beings' cognitive processes (Ahlstrom & Friedman-Berg, 2006). ATCOs have to maintain situation awareness to detect dynamic targets including aircraft in the air, vehicles on the ground at airfields and other hazards such as birds. Effective monitoring performance is foreseen as the most promising way to increase capacity and safety within air traffic services (Beier & Gemperlein, 2004). Eye movement patterns provide an insight into the ATCO's cognitive information processing through their human-computer interactions on the remote tower operations (Komogortsev & Karpov, 2013; Yu et al., 2016).

5.2.3 Monitoring Performance and Perceived Workload

Air traffic activities are constantly evolving with different traffic types, traffic volumes and weather changes. Therefore, ATCO's have to deal with more and more information that could cause a significant increase in their workload. Appropriate interface design in ATM systems can discharge ATCO cognitive loads and enhance SA by facilitating a better match between task demands and cognitive resource (Kaber et al., 2006). Effective coordination of human-computer interaction is crucial to the successful implementation of innovative systems in the MRTO environment. Interface design must apply holistic approaches to facilitate distributed cognition coordination in rapidly changing situations (Langan-Fox, Canty, & Sankey, 2009), as high performance in conflict detection and resolution has the potential to increase safety and airspace efficiency (Schuster & Ochieng, 2014). ATCOs' task performance and perceived workload might increase if technologies require operators to process more information and monitor more targets on interface displays. Increased cognitive workloads increase the risk of inattentional tunnelling, cognitive lockup, and out-of-the-loop syndrome (Endsley & Kiris, 1995). One of the most commonly used measures of operator's perceived workload is NASA Task Load Index (Hart & Staveland, 1988). Workload can negatively affect ATCOs' performance and increase operational errors (Athènes et al., 2002). Wickens (2002) defines workload as the load imposed on the limited information processing resources of the unaided (without assistance of automation) human operator described, this workload is referred to as the "baseline" or "manual" condition. Task management is directly related to mental workload, as the competing demands of tasks for attention exceed the operator's limited resources, and better multitask performance results from rapid switching between tasks (Wickens, 1999).

5.2.4 Assessing Human Performance

The Human Error Template is a formal method to identify human factors issues in the design and certification process in aviation (Stanton, 2006). The method consists of a checklist approach and comes in the form of an error template. HET works as a simple checklist and is applied to each bottom level task step in a hierarchical task analysis (HTA). The technique works by indicating which of the error modes are credible for each task step, based upon the judgement of the analysis participants. The participant simply applies each of the HET error modes to the task step in question and determines whether any of the modes produce any credible errors (Stanton et al., 2008). The strengths of the HET tool are that it is simple to learn and use, it requires very little training and it is designed to be very quick to use. The only drawback of HET is that the process can be tedious if dealing with a large amount of collected data (Stanton et al., 2010). Hierarchical task analysis is the analysis of how a task is accomplished using detailed descriptions of both manual and mental activities, task and element durations, task frequency, task allocation, task complexity, environmental conditions, and equipment involved to perform a given task. HTA is used to produce an exhaustive description of tasks in a hierarchical structure of goals, sub-goals, operations and plans. The participant then has to determine the probability of the error (low, medium or high) and the criticality of the error (low, medium or high). If the human error is marked as high for both probability and criticality, the operational step involved in the task performance is then rated as a 'concern' requiring intervention (Kearney, Li, Braithwaite, & Greaves, 2017).

5.3 Method

5.3.1 Participants

Five subject-matter experts, all qualified remote tower controllers participated in this research. The ages of participants were between 41 and 53 years old (M=47.2, SD=4.5). The working experience of participants was between 13 and 25 years (M=17, SD=5.9). The approval of the Ethic Committee was granted (CURES/1506/2016) in advance of the research taking place.

5.3.2 Apparatus

The controller working position on the Remote Tower Module is equipped with (1) the out of the window (OTW) displays consisting of fourteen active screens and one standby unit in the event of equipment failure. The displays match the Pan Tilt Zoom (PTZ) Camera resolution of 1920 x 1080 pixels with a refresh rate of 60Hz in a 220 degrees configuration with infra-camera; (2) electronic flight strip (EFS) system which is divided into two parts; one for Shannon airport and one for Cork airport; (3) radar data processing (RDP) which can be used as a distance from touch-down indicator and is divided into two parts one for Shannon and one for Cork airport; (4) a voice communication system (VCS) which was equipped with a Schmid Communications Panel. To increase ATCO's situation awareness, the borders of the display systems of EFS, RDP and OTW were distinguished by colours, purple indicated Shannon and green indicated Cork airport (figure 5.1).

Figure 5.1. MRTO including infra cameras, pan tilt zoom and radar information for different airports shown by different colours on the boarder of displays: Green for Cork airport, Purple for Shannon airport

5.3.3 Task Decomposition of MRTO

Six focus group sessions were held, and participants were supplied with the HTA and HET methodology which consisted of the step-by-step descriptions of task decomposition, taxonomy modes of human errors, a flowchart showing how to conduct an analysis using the method, an example of an analysis carried out using the method and an example output of the HET format. Participants were also given a HTA describing the action stages involved in both remotely controlling a commercial aircraft landing at Shannon airport and simultaneously controlling another aircraft departing from Cork airport from an RTC located at Dublin airport. The participants were also provided with access to the MRTO module located at Dublin airport to remotely shadow control at Shannon and Cork airports simultaneously to validate timing and task breakdown in the HTA. Hierarchical task analysis provides a detailed description of the operational actions to achieve the goals (Stanton, 2006; Stanton et al., 2008). The task decomposition involves the breakdown of the task of simultaneously controlling two aircraft located at different airports. It attempts to explain how to achieve the goal of safety by completing each operational action and noting the time required to complete each activity. The specific time needed to complete each step allows the assessment of the criticality of time-limited situations for multiple task performance. ATCO's attention distributions has to shift between airports and tasks to maintain safety of operations.

5.3.4 Research Design

This project applied Saab's remote tower systems consisting of a camera array, pan/tilt/zoom cameras and signal light guns at Cork and Shannon airports controlled from a Remote Tower Centre (RTC) at Dublin airport. The RTC is equipped with Out the Window visualisation, an electronic flight strip system and an air/ground and ground/ground voice communication system for the appropriate Cork and Shannon VHF frequencies and sector coordination functions respectively. Five subject-matter experts, all air traffic controllers, applied Hierarchical Task Analysis to break down the scenario into operational steps. ATCO's operational behaviour and their interaction with the various controller working position components including VCS, EFS, OTW, RDP, and PTZ were analysed. The HTA operational steps for simultaneous departing and arriving aircraft from two different airports, including time (in seconds) to complete the tasks, were then integrated with the twelve error modes of HET for criticality analysis (low, medium and high) and probability (low, medium and high). Participants had to determine the likelihood of the error and the criticality of the error for each individual operational step of HTA. If the error mode is given a high rating for both probability and criticality, then it is rated as a 'concern', meaning that it requires attention in order to assure and improve safety. If the error mode is given a low rating for both probability and criticality, it will be marked as

‘Pass’ (Stanton et al., 2017). Pass is defined as an error whose effects would not endanger safety (scores between 1 and 4). Conversely, Concern is defined as those errors where there was a high probability of occurrence and have the potential to endanger safety (scores between 6 and 9). ‘Concern’ highlighted design issues (hardware, software or operational procedures) which could lead to critical human factors accidents/incidents. These concerns should prompt the designer/regulator to consider changes to, or redesign of interfaces, procedures, and/or ATCO training to mitigate the impact of these errors during multiple remote tower operations (Figure 5.2).

		Low 1	Medium 2	High 3
Likelihood	Low 1	1	2	3
	Medium 2	2	4	6
	High 3	3	6	9
		Criticality		

Figure 5.2 The likelihood and criticality matrix with the Pass (1-4) and Concern (6-9) respectively highlighted in green and red on Human Error Template (HET)

NASA Task Load Index (TLX) was applied to evaluate ATCOs’ perceived workload between MRTO and physical tower operations. The high density of traffic and dynamic aircraft manoeuvres in terminal airspace will increase ATCO’s perceived workload, as controllers face additional challenges which may decrease controller’s performance and create safety concerns. NASA-TLX is a popular technique for measuring subjective perceived workload including Mental demand, Physical demand, Temporal demand, Performance, Effort and Frustration. The participants were required to evaluate their perceived workload between MRTO and single tower operations after each trial. By analysing these six dimensions, it is possible to understand the various safety concerns in relation to perceived workload and task performance.

5.4 Results and Discussions

MRTO was performed by a single ATCO simultaneously providing air traffic services to both Shannon and Cork airports. The integration of PTZ with OTW augmented visualisation reinforced by RDP and EFS technology provided the necessary technical supports for the provision of air traffic services remotely. The existing data links and communications network delivered the required information without any degradation to the standard of air traffic services. HTA and HET were conducted at the MRTO centre at Dublin airport to allow participants validate the applicability of the operational steps involved. Furthermore, NASA-TLX was applied to evaluate ATCOs' subjective workload at the end of task completion. The objective of this research is to understand the limitations of human-computer interaction and safety concerns related to human performance on multiple remote tower operations.

5.4.1 Task Analysis of Single Controller Performing MRTO

The task under analysis is 'one air traffic controller safely controlling a commercial aircraft landing at Shannon airport (EINN) while simultaneously controlling another commercial aircraft departing from Cork airport (EICK) from a RTC situated at Dublin airport. In order to distinguish the actions between Cork airport and Shannon airport colour coding was used, green colour represents operational steps related to Cork, and the red colour represents operational steps related to Shannon. The use of augmented visualisation via PTZ operation is a new HCI issue and its impact on task performance and perceived workload does not exist in traditional physical towers (Marchitto et al., 2016). Once the overall task goal of performing multiple remote tower operations was specified, the next step was to break the overall goal down into meaningful sub-goals (Stanton et al., 2004). In the task, “simultaneously Landing at EINN and Departing from EICK”, the overall goal was broken down into 51 sub-goals. There are 51 operational steps for ATCOs to complete including 27 actions associated with the landing at Shannon and 24 actions associated with the departure from Cork. All 51 operational steps must be assessed based on the twelve error modes of HET to identify potential human errors related to multiple remote tower operations. The overall goal of the task was broken down into the sub-goals. The bottom level of any branch of a HTA should always be an operational action (Stanton et al., 2017). Within the sub-goals for one ATCO performing “Simultaneously Landing at EINN and Departing from EICK”, there were 54 bottom level operational actions to be completed within a time window of 262 seconds (see appendix). Each operational action contains lots of challenging cognitive and physical demands, these task demands may increase ATCO’s perceived workload and decrease performance.

5.4.2 Analysis of Human Performance on Multiple Remote Tower Operations

The HET matrix was constructed with the vertical-axis assigned as ‘likelihood’, while the error ‘criticality’ index was placed on the horizontal-axis. Likelihood and criticality were combined through a multiplication process (likelihood x criticality) to give a ‘Pass’ or ‘Concern’ of predicting error related to HCI design on MRTO. A condition determined through the HET to have achieved a likelihood and criticality combination between 1 and 4 was assigned as ‘Pass’, a score between 6 and 9 classified as ‘Concern’. An example of operational step 1.2.4 Scan of EINN OTW and RDP is shown as table 5.1.

Table 5.1. Example of HET output on Scan OTW and RDP on Multiple Remote Tower Operations

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.2.4 Scan of EINN OTW + RDP (5 seconds)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CONCERN
				H 3	M 2	L 1	H 3	M 2	L 1		
Fail to execute	V	No check on EINN	Possible Runway incursion		V			V		V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion	V			V				V
Task executed in wrong direction											
Wrong task executed	V	Scanning Cork thinking it is Shannon	Possible Runway incursion		V			V		V	
Task repeated	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning Cork thinking it is Shannon	Possible Runway incursion		V			V		V	
Task executed too early	V	Scanning of Shannon is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of Shannon is done at a later stage	Delayed situational awareness			V			V	V	
Task executed too much	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion		V			V		V	
Misread information	V	Scanning without paying attention	Possible Runway incursion		V		V				V
Other (extra unexpected calls)		…if increasing workload, the likelihood of certain error modes may increase as well	depending on the error type, feed in turn into the criticality of the error…		V			V			

The majority of operational steps are marked as PASS with medium likelihood and low criticality. Only two error modes raised safety concerns in the HET for MRTO, these are completion of a runway scan prior to a runway operation with an associated concern of task executed incomplete and Scan of EINN OTW and RDP in five seconds with an associated concern of misread of information (table 5.1). These two concerns, task execution incomplete, raised a concern (score 9) with a high likelihood for incomplete scan of EINN's runway (score 3), with high criticality of runway incursion (score 3); and misread information (score 6) for medium likelihood (score 2) of scanning without paying attention with high criticality of runway incursion (score 3). Furthermore, the time frame of each operational step identified in the HTA is under normal operations, it is likely that should a critical event occur or an unusual or abnormal pilot request to ATC occur, there is potential for workload to increase and time pressure to become more acute. Each operational step was expected to be finished within a specific time frame. Though the majority of operational steps are marked as PASS with medium likelihood and low criticality, some of these, such as task repeat on scan Shannon runway were time consuming leading to task executed too late and reduced situation awareness, these also increased ATCO workload as some steps require crosschecking to assure safety.

The results of HTA and HET demonstrate that advanced technology integrated with augmented visualisation (PTZ, OTW, RDP and EFS) design improved ATCO's monitoring performance for controlling aircraft from two airports simultaneously. A fundamental principle for the introduction of any new technology is that it must first achieve at least the same level of safety of air traffic services provision as that which is provided using the traditional physical tower. The analysis of human performance using HET can provide the evidence, arguments and assumptions to support this principle. During the trials the air traffic controllers and the RTC project team were governed by the same safety management policies, principles and procedures that exist for Local Tower operations. There were no safety occurrences during the trials, albeit there were some safety concerns due to time pressure and the prioritisation of operational steps for multiple tasks. An important technical requirement is that the visual presentation of aircraft and vehicles by the remote tower system shall not exceed the 1,000 milliseconds of end-to-end delay in order to fit the requirements of safety assessment. There is a requirement for further research on ATCO's visual behaviours related to human performance on MRTO (European Aviation Safety Agency, 2015).

5.4.3 ATCO's Perceived Workload on Multiple Remote Tower Operations

The results of ATCOs' perceived workload between single tower and multiple remote tower operations by NASA-TLX is demonstrated in table 5.2. The test of normality for paired samples' differences was verified by using Shapiro-Wilk test, and the results showed that all six dimensions of NASA-TLX do not go against normal distribution ($p > 0.05$). Therefore, a paired T-test could be applied to analyse the differences in the six dimensions of NASA-TLX. The results demonstrated that there were significant differences for ATCO mental demand ($t=2.955$, $p=0.006$, $d=0.540$), temporal demand ($t=12.181$, $p<0.001$, $d=2.224$), effort ($t=14.203$, $p<0.001$, $d=2.593$) and frustration ($t=14.050$, $p<0.001$, $d=2.565$) between multiple remote tower and physical tower operations. However, there were no significant differences between ATCO physical demand ($t=1.510$, $p=0.142$) and performance ($t=-1.044$, $p=0.3055$) between multiple remote tower and physical tower operations (figure 5.3). MRTO operational tasks require involved more moving targets and more monitoring tasks than a physical tower operation, this means the ATCO must work harder to maintain safe separations in MRTO operations, this can induce additional pressure on ATCOs which may lead to them experience stress, fatigue and annoyance (Cao, Chintamani, Pandya, & Ellis, 2009). These may explain the significant higher mental demand, temporal demand, effort and frustration scores on MRTO than in a traditional tower operation. MRTO ATCOs have to maintain the same level of performance to ensure the safety of operations but at the cost of higher cognitive loads instead of physical demand. Previous research demonstrated that low workload had a negative influence on performance as it can aggravate boredom, and high workload can result in poor performance due to stress or overload (Eggemeier, 1988); however, high workload might provoke a strategy shift so that the operators perform well (Moehlenbrink, Papenfuss, & Jakobi, 2012). The high density of traffic and dynamic aircraft manoeuvres in terminal airspace will increase ATCO's perceived workload. This research found that NASA-TLX may reflect different components of workload including 6 dimensions and it may not co-vary with measures of all aspects of performance (Hart, 2006).

Table 5.2 T-Test of six dimensions of NASA-TLX between multiple remote tower operations (MRTO) and single physical tower operations

Dimensions	Towers	Mean	SD	N	T-Test				
					t	df	p	SE	Cohen's d
Mental demand	MRTO	46.833	9.781	30	2.955	29	0.006	3.046	0.540
	Single tower	37.833	13.814						
Physical demand	MRTO	31.667	7.350	30	1.510	29	0.142	2.097	0.276
	Single tower	28.500	7.673						
Temporal demand	MRTO	74.333	17.157	30	12.181	29	0.000	3.325	2.224
	Single tower	33.833	14.779						
Performance	MRTO	85.000	3.714	30	-1.044	29	0.305	1.596	-0.191
	Single tower	86.667	7.112						
Effort	MRTO	84.167	5.884	30	14.203	29	0.000	3.438	2.593
	Single tower	35.333	17.066						
Frustration	MRTO	71.167	18.321	30	14.050	29	0.000	3.499	2.565
	Single tower	22.000	13.038						

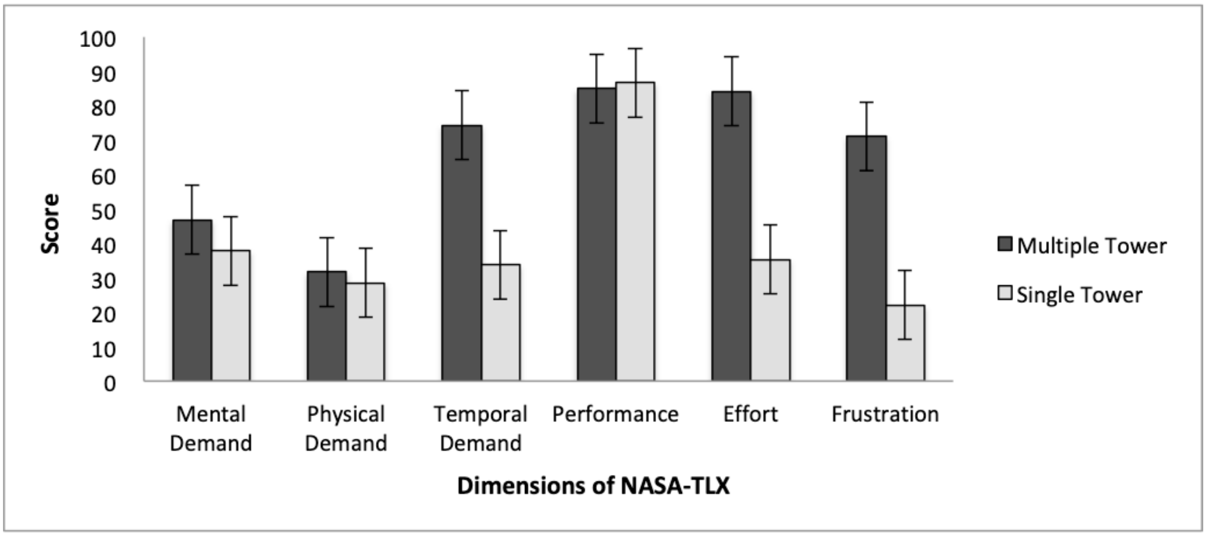

Figure 5.3 The comparison of perceived workload between single tower operation and multiple remote tower operations

The results demonstrated the concept of MRTO is applicable for providing both air and ground movement control for two low volume airports. However, how much is too much when it comes to tasks for a single controller? MRTO is safe whilst operations are routine, the evolution of a critical event at one or two airports has the potential to overload the single ATCO, this requires additional study and analysis before MRTO operations can be deployed (Kearney & Li, 2018). The development of new remote tower technology is designed to reduce ATCO's workload through augmented vision presented on OTW, RDP and EFS. However, the added complexity of multiple tasks did create more cognitive loads to ATCOs to process huge volumes of information (Wiener, 1988; Li, Kearney, Braithwaite, & Lin, 2018). Augmented visualisation design of RTM allows ATCOs to change the size of the screen for selected airports, this innovative technology has significantly increased ATCO's task performance. However, there are also some potential risks related to HCI and human performance and these require further research to precisely identify these impacts and suggest suitable mitigation strategies to defend against the risks (Ltifi, Kolski, & Ayed, 2015).

5.5 Conclusion

The application of remote tower technologies can assist ANSP's achieve cost efficiency and safety requirements as mandated through the EU Single European Sky project. This research demonstrated that augmented visualisation using panorama video cameras did provide sufficient technical support for a single ATCO to perform tasks initially planned to be achieved by four ATCOs in a traditional tower, however, the demands of multiple tasks also induced significant workload. It must be stated that this research is based on normal operations and does not consider the impact of unusual situations, critical events or emergencies during operations. Should an unexpected event occur, it is reasonable to expect that workload may increase thus having the potential to negatively impact on ATCO's performance. This creates a need for further research on how to relieve ATCO's workload. MRTO has been proven as safe as the local tower operation in providing air traffic services. The novelty and flexibility of remote tower technology may allow regulators to be creative in adapting safety regulations and ANSP's to be more operationally agile in the management of varying traffic volumes. Nevertheless, the evolution and deployment of MRTO systems requires a cautious balance between cost-efficiency and the potential impacts on safety, capacity, and human performance.

CHAPTER VI

Multiple Remote Tower for Single European Sky: The Evolution from Initial Operational Concept to Regulatory Approved Implementation

6.1 Introduction

The initial concept of remote tower operations was started by the research proposal of Virtual Control Towers over 20 years ago (Kraiss & Kuhlen, 1996). The paradigm of remote tower operations will allow air traffic services (ATS) be delivered remotely without direct observation from a local tower. The emerging technology of remote towers developed slowly during the early stages but in recent times has taken a leap forward with some single airport virtual tower operations. SeaRidge technologies in partnership with HungaroControl have secured certification for the provision of remote tower live operations without restrictions; SAAB has provided London City airport with its digital tower platform to begin its landmark replacement of the conventional tower with remote solution. Norway’s air navigation service provider Avinor has collaborated with Indra, Naviair and Kongsberg to implement remote tower provision at up to fifteen low density airports from one central location (Otsby, 2016). Italian air navigation services providers ENAV successfully tested “Remote Airport Concept of Operation” (RACOON) which validated multiple mode operations at Milan Linate airport from Milan Malpensa (SESAR, 2016). Additionally, remote tower operations to medium size aerodromes were demonstrated by DFS at Saarbrücken Airport and by LVNL for Eelde Airport in active as well as in passive shadow mode based on operational procedures used in their respective conventional towers (SESAR, 2015a).

The development of Augmented Vision Video-panorama technologies has increased the monitoring capabilities of remote tower operations (RTO). Both monitoring and communication are important tasks of ATCOs, the concept of MRTO raised a safety concern for human performance in higher traffic environments in this virtual environment (Papenfuss & Friedrich, 2016). The identification of visual properties used by ATCOs to monitor aircraft for landing and manoeuvring at airports are critical to aviation safety. ATCO's use Out the Window visualisation (OTW) supported by radar data processing (RDP), electronic flight strips (EFS) and a communications network (TEL) to provide air traffic services in the airfield environment (Ellis & Liston, 2016). It is likely that ATCOs' monitoring performance is influenced by the system design of remote tower centre (RTC) and the performance of multiple tasks simultaneously would require the sharing of cognitive resources of the controllers. The concept of distributed cognition seeks to understand the structure of cognitive system and extends the application to encompass interactions between resources and information in the operational environment (Hollan, Hutchins, & Kirsh, 2000).

The motivations of this research are to understand the limitations of controlling simultaneous traffic patterns at two airports by a single ATCO, to demonstrate how the implementation of the advanced technology impacts safety, capacity and human performance, and how to conduct safety assessment of MRTO in order to secure regulatory approval for live operations. Based on the concept of remote tower operations, multiple remote tower operations (MRTO) offer further solutions for cost efficiency of air traffic services for small and medium size of airports. The new technology will allow one air traffic controller (ATCO) control two or more airports at the same time during low traffic volumes. The feasibility of controlling two airports simultaneously was demonstrated successfully with a special focus on the visual attention of ATCOs and the controller working position design (CWP) related to ATS task (Moehlenbrink & Papenfuss, 2011).

6.2 Background of Policy and Practice

This Multiple Remote Towers research was sponsored by the Single European Sky ATM Research Program (SESAR) and the ATM Operations Division of the Irish Aviation Authority. The Remote Tower Centre (RTC) was located at Dublin Air Traffic Services Unit in excess of 100 nautical miles away from the two airports at Shannon and Cork where the services were provided simultaneously (figure 6.1). Cork airport is a H24 international airport with aircraft types up to medium weight category such as Boeing 737 and Airbus 320. Total movements in 2016 were 50,242. Shannon is a H24 international airport with aircraft types up to the heavy weight category such as Airbus A330, it handled 25,059 movements in 2016. This research will contribute to the objectives for in sequence and simultaneous remote provision of ATS for multiple aerodromes as outlined in the Operational Improvement Step (OIS) SDM-0205 linked to SESAR Work Package (WP) 06.09.03 of the EU ATM Master Plan.

Figure 6.1. The Remote Tower Centre located at Dublin Airport in excess of 100 miles away provided air traffic services for both Cork and Shannon airports

6.2.1 The Evolution of Remote Tower Operation

Air traffic in Europe has consistently increased since the 1990s. The Single European Sky (SES) initiated a reorganisation of European airspace based on traffic flows instead of national boundaries and proposed additional measures for air traffic management to achieve key objectives of enhanced efficiency and capacity while improving safety performance. SES regulations focussed on efficiency, capacity and safety have increased cost pressure on air navigation service providers and require them to be more innovative in their approach to the provision of air traffic management services. Many air navigation service providers (ANSPs) have developed automated systems using video-panorama cameras for synthetic outside view, to increase capacity at airports and to improve cost efficiency by minimising personnel to meet cost efficiency targets (Leitner & Oehme, 2016). This has seen increased attention in remote tower research over the last 20 years.

The concept of remote tower operations is that an ATCO can control any airfield from a distant virtual control centre. The view of the airfield under control is displayed in real time on screens and air traffic and vehicle movements can be controlled. This concept is predominantly appropriate for lower volume airports. Therefore, the control of multiple airfields can be centralised permitting capital and operational costs savings. Consequently, the visual features of cues and objects which ATCOs must identify for safe operations are significant influencers of the requirements for surveillance cameras, data-communication links and display systems in a remote tower centre (Van Schaik et al., 2016). The concept of an advanced remote tower was developed for airports with fewer than 25 movements at the mean busy hours with a mix of visual flight rules and instrument flight rules. Technology advances can facilitate the image-video resolution for visual detection but not for recognition.

The German Aerospace Centre also has evaluated the metrics of aircraft on Dutch roll, Route, Decline, Landing light, Flight path and Gear status to evaluate the performance of ATCOs' visual identification by remote tower module. To test the feasibility of the RTO concept, V-2 feasibility of human-in-the-loop have been conducted and validated for single remote tower operations (Friedrich & Mohlenbrink, 2013; Friedrich, 2016). NextGen is concerned with the diverse aspects of tower control including human-computer interaction, situation awareness, cost of airport control tower, safety management and capacity variation. NASA has also examined remote tower operations by studying alternative approaches for improving runway safety at Los Angeles International Airport (LAX) under future flight central program (Dorighi & Rabin, 2002). The preliminary research demonstrated that remote tower operations can provide substantial economic benefits compared to the traditional operations of local air traffic control towers, as NextGen proposed an innovative concept to address airport capacity problem by introducing an integrated tower information display providing weather and surveillance data as decision support tools (Nene, 2008). The concept of remote towers exhibited encouraging improvements in communications and departure rates with no differences in perceived workload, effort, safety and situation awareness (Nickelson, Jones, & Zimmerman, 2011). This option may offer operational cost saving, and the level of services provided to pilots operating under visual flight rules might be reduced.

6.2.2 The Cost Efficiency of Multiple Remote Tower Operations

Multiple Remote Tower Operations is an alternative solution to enhance safety and capacity at small/medium airports in a cost-efficient manner. This new technology allows one ATCO control one or more small airports from a remote location (Fürstenau, 2016). Furthermore, the building and operational costs of remote tower facilities is much lower compared with a traditional physical tower. However, there has been growing concern by safety regulators as to how human performance is managed using these new technologies. There is a requirement to develop a safety case and address concerns that multiple remote tower operations may increase operational risk for ATCOs (SESAR Joint Undertaking, 2013, 2015b).

Over 75% of regional airports with lower than one million passengers are currently making a loss. Cost of ATC services present the major portion of a regional airport's overall operating costs. The operational services of regional airports are similar, so the costs can be shared by relocation of the ATC function of two or more airports to a shared facility of multiple remote tower centre. The introduction of multiple remote tower operations is mainly driven by a desire reduce ATS operational costs in order to meet Single European Sky cost reduction requirements. However, the SESAR assessment report of remote tower for multiple airports added additional safety specifications as requirements (Ziegler, 2016). IAA has conducted an analysis of the total costs of building and operating a physical tower by compared with the costs of remote tower. The result demonstrated that remote tower operations reduces costs significantly on the buildings, infrastructure and operational manpower in the order of €1.3 million per year (table 6.1). Furthermore, Federal Aviation Administration (2012) revealed that the construction of a single control tower under federal contract might take three to five years with approximately $4.2 million plus the average annual operational costs and maintenance costs of $185,000 and several hundred thousand dollars for annual controllers' compensation.

Table 6.1: The comparison of cost-efficiency between existing tower and remote tower

	Build	Equipment	Manpower
Traditional Tower	Roughly cost £12M to Build. To assume 10% annual running cost for the building is reasonable £1.2M a year.	Usual Communications, Navigation, Surveillance and Flight Data Processing Systems.	Typical manning is 8 to 10 staff per H24 position.
Remote Tower	Build costs will reduce significantly as only a mast needed to house the cameras. Estimated cost of mast £2M saving £10M. To assume 10% annual running cost for the Mast is reasonable e.g. £200K a year saving £800K a year. In summary if the tower is depreciated over 30 years, saving is (12-2)/30 = £333K in CAPEX, plus £800K in OPEX so £1.33M a year.	Additional CAPEX is £2M. If the remote tower system is depreciated over 8 years, additional costs is 2/8 = £250K in CAPEX, plus £200K in OPEX so £450K a year. There should be potential to save on some of the Communications, Navigation, Surveillance and Flight Data Processing Systems Costs via centralisation which will offset some of the increase in network costs.	Remote Towers will facilitate staffing efficiencies. The objective is to crew to workload such that operational staff are always busy within allowable safety limits. For the IAA example of Cork and Shannon controlled from Dublin we anticipated a saving of 4 ATCO's or £400K a year.

6.2.3 Safety Assessment of Multiple Remote Tower Operations

The Safety Assessment Report for Multiple Remote Towers (SESAR Joint Undertaking, 2015b) contemplated the availability of surveillance data to support ATCOs task performance in bad weather conditions (Ziegler, 2016). The IAA ANSP as sponsor and project coordinator is the ANS provider for Dublin, Cork and Shannon airports. The Dublin Airport Authority (DAA) as the airport operator for Cork Airport and Stobart Air are an international commuter airline. The Shannon Airport Authority (SAA) was involved as a stakeholder. A Demonstration Plan was prepared to describe how the live trial exercises would be organised, conducted, supervised, and assessed. This plan focused on safety, capacity, cost efficiency and human performance concerns. The safety case report is a structured argument, supported by a body of evidence that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment. It provides a comprehensive and structured set of safety documentation which is aimed to ensure that the safety of a specific system or equipment is safe for operational deployment. It will also establish the requirements for safety monitoring following transition into operation and for the entire life cycle of the system through to decommissioning (European Aviation Safety Agency, 2014, 2015b).

For delivery of a safety argument for approval the IAA project team developed a “safety case” by applying the Eurocontrol safety assessment methodology (SAM) to provide safety assurance that the introduction of any new technological systems or changes to these systems are proven to be tolerably safe for service provision. The safety assessment methodology of current research follows a structured step wise process as followings (figure 6.2);

(1) Safety Plan defines a safety programme that is planned, integrated and developed in conjunction with other design, development, production and quality control activities. It details safety activity timelines and deliverable in accordance with the higher project plan. It requires regulatory endorsement and approval.

(2) Functional Hazard Assessment (FHA) records the functions to be performed by the system, the effects of identified hazards on operations, including assessment of the severity of the hazards effects and also records the derived safety objectives, i.e. determines their acceptability in terms of the hazards maximum frequency of occurrence, derived from the maximum frequency of the hazards effects.

(3) Preliminary System Safety Assessment (PSSA) produces Safety Requirements and Assurance Levels for the system elements and records the evidence, arguments and assumptions to verify that the proposed solution will meet its Safety Requirements. It also provides the arguments to support the claim that the system will not affect the safety of the ATM system during installation and commissioning.

(4) System Safety Assessment (SSA) records the evidence, arguments and assumptions to verify and validate that the system design configuration will meet its Safety Requirements. It also describes specific operating and maintenance requirements necessary to assure safety and provides arguments to support the claim that the system will not affect the safety of ATM during the transition to operational use. In addition, the SSA provides details of the Transition Plan for introducing the system into service.

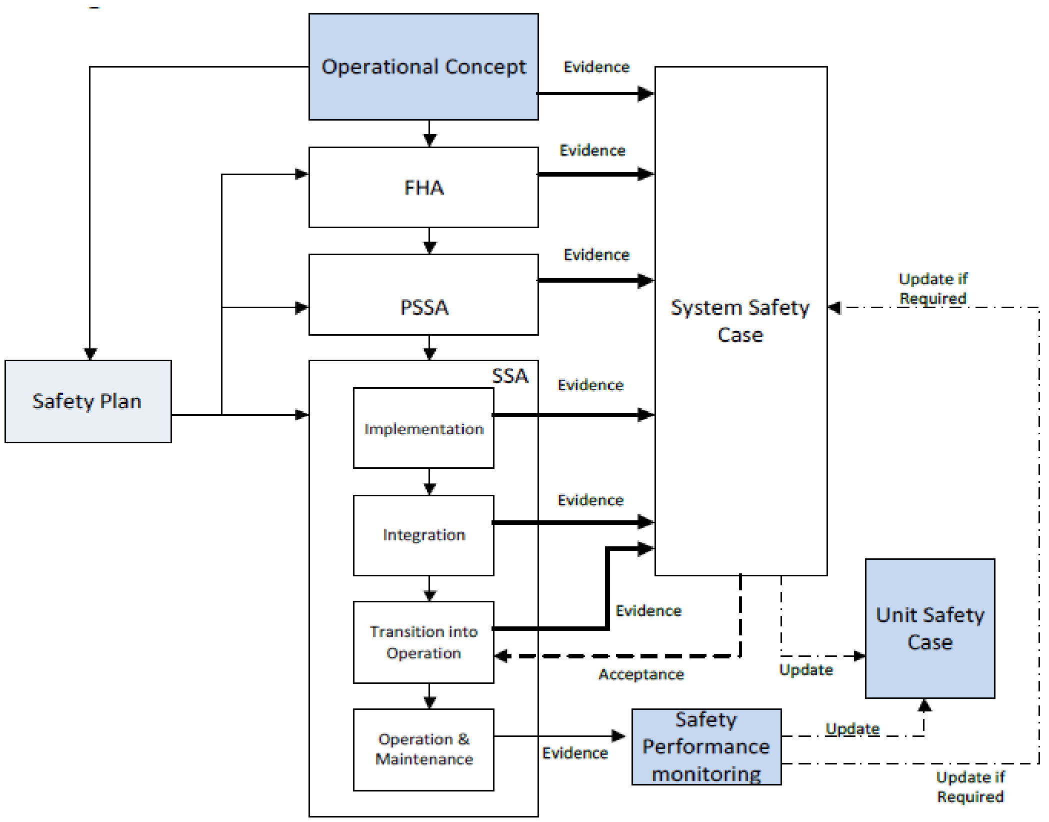

Figure 6.2. Safety assessment Methodology applied by IAA Terminal Services

6.2.4 The Processes of Regulatory Approval for Implementation

The regulatory body responsible for the regulation of aviation in Europe is the European Aviation Safety Agency (EASA) based in Cologne, Germany with offices in Brussels. It has been providing safety regulation for member states in Europe since 2002. It is an agent of the European Union, its mission is to ensure the highest common level of safety protection in aviation for EU citizens. EC Regulation 549 /2004 ‘The Article-4 of Framework Regulation mandates that each European Communities State establish a National Supervisory Authority (NSA) with responsibilities for the supervision and safety oversight of Air Navigation Service Providers which provide air traffic control, airspace management and air traffic flow management services (Pellegrini & Rodriguez, 2013).

The Irish Department of Transport (DoT) have designated the Safety Regulation Division (SRD) of the Irish Aviation Authority as the NSA for Ireland with Aeronautical Services Department (ASD) specifically charged with the oversight of all ANSP’s nationally. External oversight of the IAA is carried out by two independent bodies, namely; the International Civil Aviation Organisation (ICAO) a body of the United Nations (UN), who conduct safety oversight audits of all States' safety regulation authorities worldwide and EASA, who routinely audit the IAA regulatory Body. In accordance with internal ANSP safety processes the safety case report was submitted to its safety management unit (SMU) to ensure all evidence and arguments were met and that all identified hazards and their subsequent effects were assessed, documented and safety requirements implemented prior to operational usage of the multiple remote tower concept. Any open issues were highlighted and detailed in the safety case report ahead of the trial being conducted. During the trial, safety levels were monitored by the implementation of a shadow operation whereby the actual towers of Cork and Shannon were manned by appropriately qualified and competent controllers while service delivery was being provided from Dublin RTC (European Aviation Safety Agency, 2014; SESAR Joint Undertaking, 2015b). In the event of any operational or safety issue arising, these traditional towers were immediately available to assume operational control.

Safety Regulatory approval would be dependent upon the provision of evidence of in service trials which, this evidence was collected through the deployment of large scale demonstration (LSD) trials of remote tower operations for multiple airports. These involved the provision of air traffic services at two airports at the same time utilising innovative technological solutions. A dedicated team of operations and technology experts completed 50 trials demonstrating multiple remote tower operations in real time, specifically, air movement control (AMC) and surface movement control (SMC) at Shannon and Cork airports simultaneously from the remote tower centre at Dublin Airport. Trials were only permitted following the submission of a detailed and comprehensive safety argument, submitted by Terminal Services Operations (European Aviation Safety Agency, 2015a; SESAR Joint Undertaking, 2013) to the Irish Supervisory Authority.

6.3 Methodology of Demonstration

The demonstration of multiple remote tower operations was provided in sequence or simultaneously for both Cork and Shannon airports during periods of low traffic density building on the SESAR solution package for remote tower for single and multiple airports. Out the window visualisation supported by radar and electronic strip technology and the existing data and communications network will provide the necessary environment for the provision of ATS remotely and without degradation. The project was supported by a safety case which was approved by the NSA for Ireland. Fifty live trial exercises involving up to 500 aircraft were conducted between June and September 2016.

6.3.1 Participants

Three qualified and licensed air traffic controllers holding appropriate ratings on both Cork and Shannon airports participated in the live trial demonstrations in accordance with (EU) 805/2011 and EASA NPA 2015-04. SAAB systems provided familiarisation and HMI training on the RTC CWP and ATCOs were certificated accordingly. Train the trainer certificates were granted to specialists in IAA. This training combined in conjunction with the training specified in all relevant aspects of the RTC including the electronic strip system continued up to the demonstration commencement date. The approval of Science and Engineering Research Ethics Committee was granted (CURES/1506/2016) in advance of the research taking place.

6.3.2 Apparatus

Remote Tower Module (RTM): This project applied Saab's remote tower systems consisting of a camera array, pan/tilt/zoom (PTZ) cameras and signal light guns (SLG) at Cork and Shannon airports controlled from a Remote Tower Centre (RTC) at Dublin ATS unit. The RTC is provided with Out the Window visualisation (OTW), Electronic Flight Strip (EFS) System and an air/ground and ground/ground voice communication system (TEL) for the appropriate Cork and Shannon VHF frequencies and sector coordination function respectively (Figure 6.3). The RTC contained two panoramic OTW display comprised by 15 full HD LED display screens (14 active & 1 spare) which provide a panoramic 360 degree view of the selected airport and its surrounding airspace in a 208 degree configuration. Therefore, one ATCO could provide services for both Cork and Shannon using one OTW display.

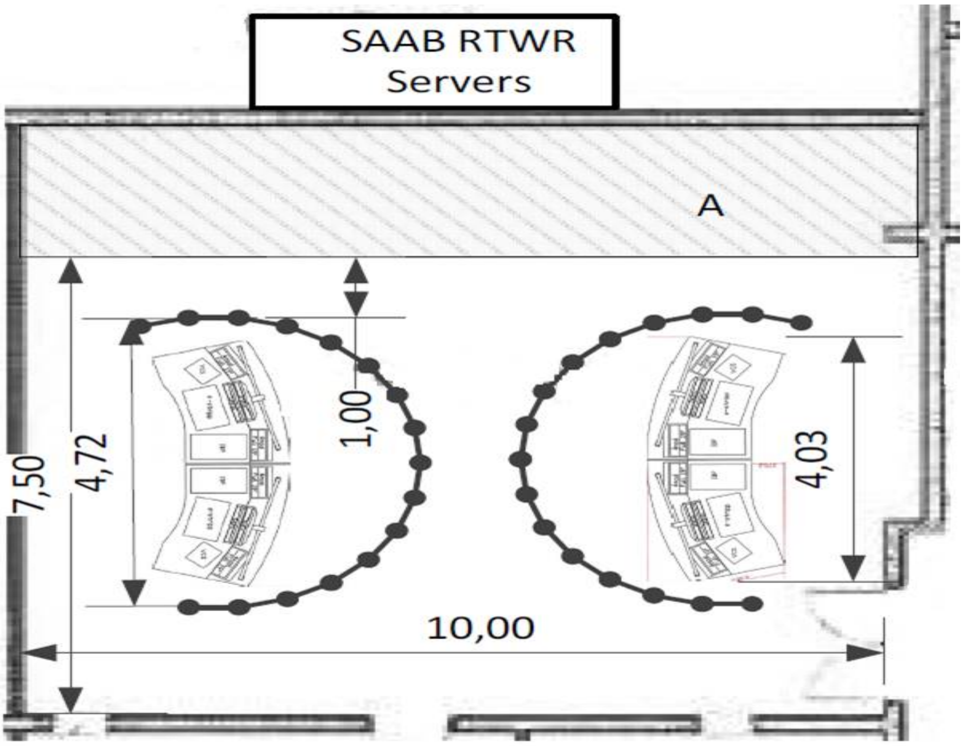

Figure 6.3. Remote Tower Centre OPS Room and Test & Validation Room

The OTW displays are normally used to present the images from the 14 cameras, while the last display is a stand-by unit in the event of equipment failure. The displays match the camera resolution of 1920x1080 pixels, and have a refresh rate of at least 60Hz. The displays are mounted in portrait mode to match the portrait-mounted cameras. The PTZ cameras controlled from RTC allow the ATCO a 30 times zoom (optical), 90 degrees up and 80 degrees down tilt, panning 360 degrees and selection of pre-defined sweeps and/or positions. The PTZ view is displayed on the OTW display (Figure 6.4). Each RTM is equipped with the Saab's e-Strip which consists of a top bar, a vehicle map, a strip board and a bottom bar. The top bar contains a settings dialogs for changing role and runway combination, as well as certain status information. The top bar also contains two buttons that will open side windows which are toolboxes from where new strips can be created and old strips can be recovered. The bottom bar contains a slider for adjusting the screen brightness. A vehicle map displays a graphical view of the runway and taxiway. Vehicles can be added, removed to/from the vehicle map or moved within the vehicle map. The radar target tracking presents information from the radar display as an overlay in the visual presentation, linked with the visual tracking. This enables the aircraft to be tracked with label attached providing radar information including call sign and altitude providing additional support to visual observation. The Flight Data Processing (FDP) includes the display of messages accessed by a pull-down display on top of the visualisation display. Data displayed includes Flight Plan information and NOTAMS.

Figure 6.4 Controller Working Position (CWP) and Out of the Windows (OTW) screens of Remote Tower Module in RTC

Eye Tracking Device: The device used to collect ATCOs' eye movements and track their visual behaviours is a light, mobile, head-mounted eye tracker developed by Pupil Lab. It allows participants to freely move their head and is composed of two cameras, one focused on the pupil and the other one the environment. Both cameras can be moved to accurately get eye detection and the pilot field of vision. The software used to record data is Pupil Capture 9.3 and the one used to process data is Pupil Player 9.3, both from the same company as the headset. The set-up of the eye camera is a 640x480 resolution for a 60 frames rate. The world camera is a 1280x720 with a frame rate of 30, however due to computer limitation, this frame rate can be flexible due to the volume of data processing and is not constant over time. The cameras are adjustable to suit different participant's facial layout and track their pupil parameters accordingly (Kassner, Patera, & Bulling, 2014).

6.3.3 Safety Case for 50 Live Exercises

The Safety Case for multiple remote tower live trials followed the SESAR standard four-part safety case approach beginning with the production of a safety plan. This framework outlines the safety case activities to be conducted for the entire Remote Tower System (people, procedures, and equipment), the specific deliverables applicable and the timescale for submission to the NSA. This was followed by the production of a functional hazard analysis which formed the basis for the setting of safety objectives and requirements for the system. A preliminary system safety assessment document was then developed leading to a final system safety assessment. Each deliverable was submitted to the NSA as it reached maturity. A hazard log was also developed which remained open for the duration of 50 live exercises so that any previously unidentified hazards could be recorded and mitigated appropriately.

General requirements regarding traffic scenarios were defined in the demonstration plan as well as the selection of Cork and Shannon airports. Traffic parameters such as traffic flows, depart/arrival ratio, visual flight/instrumental flights are realistic at both airports. The demonstration plan also described the success criteria for each live exercise and how the 50 live exercises were further divided into three batches. The first batch of exercises (numbers 1 to 5) had the objective of familiarising operational and technical personnel with the procedures to be used, and the environment in which they will be operating for SMC (table 6.2). The second batch of exercises (numbers 6 to 20) had the objective of demonstrating the applicability of integrated SMC and AMC operations with incrementally increased traffic movements mixing arrivals and departures at both Cork and Shannon airports. Flexibility in the timing of exercises was applied to maximise the variability of scenarios to be used with regard to runway in use, type of approach (instrument or visual). During this phase the simultaneous scenario (Cork and Shannon) was introduced with low traffic movements (table 6.3). A further 30 exercises (numbers 21 to 50) were conducted with the objective of building on the experience gained from previous exercises with increased traffic movements as appropriate in the sequenced and simultaneous scenarios (table 6.4).

Table 6.2: The description of batch-1 live exercises 1-5

Exercise Id	Exercise Description
001	Shannon (SNN) SMC only in Module RTM-A1
002	Cork (CRK) SMC only in Module RTM-A2
003	Control of SNN SMC in RTM-A1 & Cork SMC in RTM-A2
004	CRK SMC first then SNN SMC combined on a single position
005	CRK SMC in RTWR A2 SNN SMC in RTWR 1 with different screen configuration to exercise 003

Table 6.3: The description of batch-1 live exercises 6-20

Exercise Id	Exercise Description
006	Control of SNN SMC in RTM-A1 & Cork SMC in RTM-A2
007	Control of SNN SMC & SNN AMC from a single position in RTM-A1. No Cork Positions.
008	Control of SNN AMC & SNN SMC in RTM-A1 and Cork SMC in RTM-A2
009	Continuation of exercise 08. Hand back CRK and split SNN SMC onto RTM-A2
010	Control of SMC & AMC from a single position RTM-A1.
011	Control of SNN AMC in RTM-A1. Cork AMC in RTM-A2
012	Merge SNN AMC and Cork AMC in RTM-A2 This exercise is a continuation of exercise 11 whereby we kept control of both SNN & CRK AMC Roles but merged them onto a single position thereby making this exercise the first time Multiple AMC Control was performed from a single Remote Tower position.
013	Control of SNN AMC in RTM-A1 and CRK AMC in RTM-A2 The plan is to merge the two positions as soon as traffic allows
014	Control of SNN AMC in RTM-A1. Cork AMC in RTM-A2.
015	Control of SNN AMC in RTM-A1. CRK AMC in RTM-A2 Later SNN and CRK AMC combined in RTM-A2
016	Control of SNN AMC RTM-A1 CRK AMC RTM-A2 Later SNN & CRK AMC combined in RTM-A1
017	Control of SNN AMC in RTM-A1. CRK AMC in RTM-A2

	Later SNN & CRK AMC combined in RTM-A2
018	Control of SNN AMC in RTM-A1. CRK AMC in RTM-A2.
019	Control of SNN & CRK AMC combined in RTM-A2
020	Control of SHA AMC in RTM-A1. No Control of CRK AMC due to Low visibility in Cork which needed to be aware before actively Controlling in these conditions.

Table 6.4: The description of batch-3 live exercises 21-50

Exercise Id	Exercise Description
021	Control of SNN AMC in RTM-A1. CRK AMC in RTM-A2 initially then later in the exercise SNN & CRK AMC combined in RTM-A2
022	Control of SNN AMC in RTM-A1 CRK AMC in RTM-A2 initially then later in the exercise SNN & CRK AMC combined in RTM-A2
023	Control of SNN & CRK AMC combined in RTMA1
024	Control of SNN AMC in RTM-A1 CRK AMC in RTM-A2 Later SNN & CRK AMC combined in RTM-A2
025	Continuation of exercise 024. Control of SNN & CRK AMC combined in RTM-A2
026	Control of SNN AMC in RTM-A1 CRK AMC in RTM-A2 initially then later in the exercise SNN & CRK AMC combined in RTM-A2
027	Control of SNN AMC in RTM-A1 CRK AMC in RTM-A2 initially then later in the exercise SNN & CRK AMC combined in RTM-A2
028	Control of SNN & CRK AMC combined in RTM-A2
029	Control of SNN & CRK AMC combined in RTM-A2
030	Control of SNN & CRK AMC combined in RTM-A2
031	Control of SNN & CRK AMC combined in RTM-A2
032	Control of SNN & CRK AMC combined in RTM-A1 Control of SNN & CRK SMC combined in RTM-A2 initially then later in the exercise Control of SNN & CRK AMC & SMC combined in RTM-A2
033	Control of SNN AMC in RTM-A1. CRK AMC in RTM-A2 initially then later in the exercise SNN and CRK AMC combined in RTM-A2
034	Control of SNN & CRK AMC combined in RTM-A2
035	Control of SNN AMC in RTM-A1 CRK AMC in RTM-A2 initially then later in the exercise SNN & CRK AMC combined in RTM-A2
036	Control of SNN AMC& SMC in RTM-B2 Control of CRK AMC& SMC in RTM-A2
037	Control of SNN & CRK AMC & SMC combined in RTM-A2
038	Control of SNN AMC in RTM-A1, then Control of SNN SMC in RTM-A2 Next series of exercises is to follow the progression of workload starting with 2 Controllers at one airport and in the next exercise moving to 1 Controller per airport.
039	Control of SNN AMC& SMC in RTM-B2 Control of CRK AMC& SMC in RTM-A2
040	Control of SNN & CRK AMC & SMC combined in RTM-A2
041	Control of SNN & CRK AMC & SMC combined in RTM-A2
042	Control of CRK SMC in RTM-A1 & CRK AMC in RTM-A2
043	Control of SNN SMC in RTM-A1 SNN AMC in RTM-A2
044	Control of SNN and CRK AMC combined in RTM-A2
045	Control of SNN and CRK AMC combined in RTM-A2
046	Continuation of Ex.45 Control of SNN and CRK AMC combined in RTM-A2
047	Control of SNN and CRK AMC combined in RTM-A2
048	Control of SNN and CRK AMC combined in RTM-A2
049	Control of SNN AMC on RTA 1 and CRK AMC combined in RTM-A2 initially then later in the exercise Control of SNN & CRK AMC & SMC combined in RTM-A2
050	Control of SNN & CRK AMC & SMC combined in RTM-A2

6.3.4 Procedures

IAA normal operational practice if to apply fully redundant systems and data lines for stand-alone operations (figure 6.5). This required a procedure commencing 20 minutes before transfer of Control from the local tower to the remote tower module and involved ATCOs cross checking information from the Local Tower against information on electronic flight strips at the RTM. This was initiated and completed through a phone call from the Remote Tower. The cross check also permitted the co-ordination of information on aircraft stand allocations, transponder codes and any upcoming local training details by a flight training school at Cork airport. These cross checks were followed by a detailed handover of position(s) to the Remote Tower ATCO in accordance with current IAA operational position handover procedures including briefing on the current weather data, airfield lighting status and navaid status (10 Minutes before transfer of Control). Main air traffic control radio frequencies were deselected on the COMPAD communications system in the local tower who then temporarily reverted to operations via the Radio Backup System. This was to avoid simultaneous transmissions from two locations on a single transmitter which may cause transmitter failure.

A project consortium was established to ensure all aspects of relevant aviation activity was represented in the project. The project team consisted of Project Manager, an ATM Specialist, a Human Factors Expert and two appropriately rated Controllers who were present for the live trials. During the trials the following types of information was collected: (1) Exercise date and time; (2) Tower roles assumed in the RTC; (3) Exercise participants; (4) Weather at both airports; (5) Aircraft involved in each exercise and the timing (to the second) of events to record what actions a controller was conducting during each minute; (6) collecting ATCOs' eye movements and the debrief observations; (7) Aircraft involved in the exercise as well as recording notes on non-normal aircraft movements e.g. simulated engine failure or touch & go; (8) Completing the initial assessment of the controller impression of various aspects; (9) Compiling unexpected behaviour/results and recommendations.

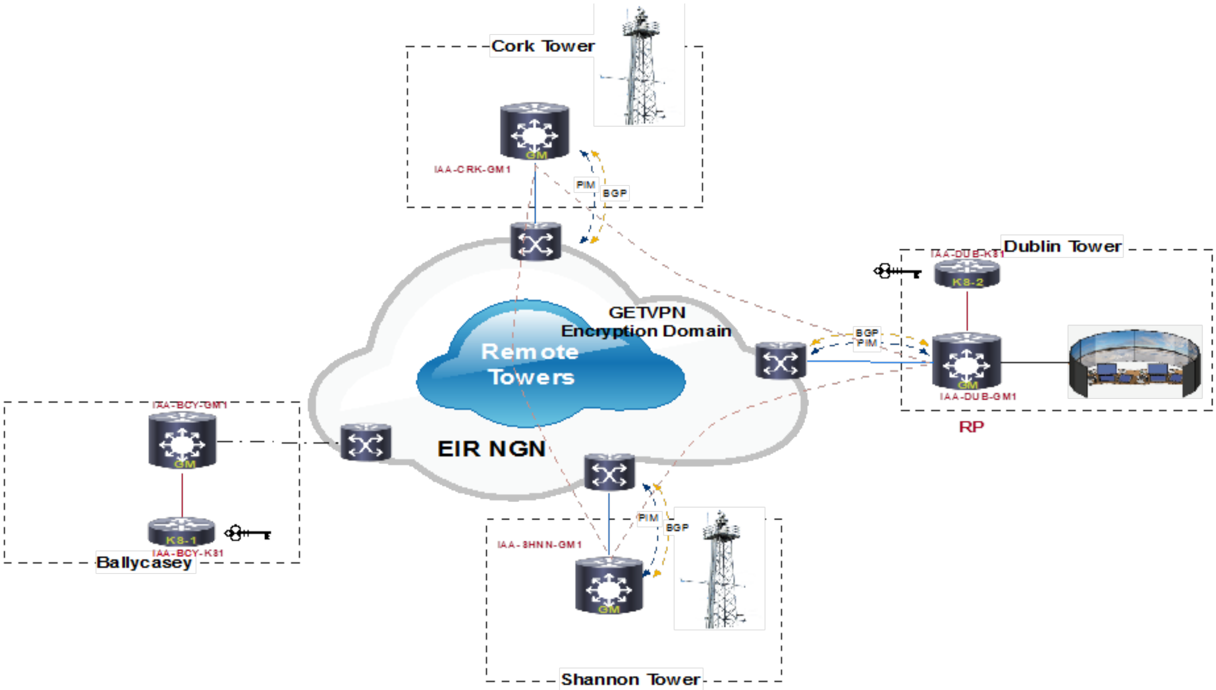

Figure 6.5. Video-Data Communications Links of Multiple Remote Towers Protected by IPsec for Data Confidentiality, Integrity and Authentication between Participating Peers

6.4 Large Scale Demonstration

The results of this research demonstrate that advanced remote technology based on human-cantered design improved ATCO's performance in monitoring and controlling more aircraft from two different airports. OTW design permits the adjustment of the percentage of the selected airports on the screens based on ATCO's preference, but they are also able to zoom-in by PTZ to enhance visual searching. Furthermore, OTW allows different colours to distinguish different airports, in this case green for Cork and red for Shannon, further increasing ATCO's situation awareness to which airport he/she is engaging. The EFS system integrates aircraft strip information with the map of runway and taxiway, providing the ATCO a clear picture of the locations of the moving targets. If an ATCO has permitted one aircraft to enter a runway, he/she will not be able to permit another aircraft moving to enter the same runway with this EFS. This is a very effective design to prevent runway incursions. The information presented by the RDP can facilitate ATCO in predicting the flow of traffic and landing time at each airport, thereby facilitating enhanced decision making in respect of simultaneous movements at both airports.

6.4.1 Eye Scan Patterns of Single ATCO Performing Multiple Operations

ATCOs' eye movements across four areas of interests (AOIs) including RDP, EFS, TEL and OTW were analysed while performing multiple tasks. A series of ANOVAs with four AOIs (RDP, EFS, TEL, and OTW) to assess single ATCO's eye movement patterns on multiple remote tower operations. The response variables are fixation count (FC), fixation duration (FD), saccade amplitude (SA), and pupil size (PS) shown as table 6.5. Fixation duration: The assumption of sphericity is violated (Mauchly's $W = .380$, $p < .001$), therefore the Greenhouse-Geisser is applied to adjust the univariate test. Results indicated no significant main effect of AOIs, $F(1.843, 60.823) = 2.192$, $p > .05$. Fixation count: The assumption of sphericity is violated (Mauchly's $W = .682$, $p < .05$), therefore the Greenhouse-Geisser is applied to adjust the univariate test. A significant main effect of AOIs, $F(2.511, 85.373) = 22.385$, $p < .001$, was found. Post-hoc comparison on AOI revealed RDP is larger than EFS and TEL ($ps < .001$). Moreover, OTW is smaller than EFS ($p < .001$) and TEL ($p < .001$). Saccade amplitude: The assumption of sphericity is not violated (Mauchly's $W = .966$, $p > .05$), therefore no adjustment is required for the univariate test. A significant main effect of AOIs, $F(3, 87) = 30.346$, $p < .001$, was found. Post-hoc comparison on AOI revealed OTW is larger than RDP, EFS, and TEL ($ps < .001$). Pupil size: The assumption of sphericity is violated (Mauchly's $W = .377$, $p < .001$), therefore the Greenhouse-Geisser is applied to adjust the univariate test. A significant main effect of AOIs, $F(2.040, 67.330) = 11.687$, $p < .001$, was found. Post-hoc comparison on AOI revealed RDP is larger than EFS ($p < .001$). Moreover, TEL is larger than EFS ($p < .001$) and OTW ($p < .001$).

Table 6.5. Descriptive statistics of mean and standard deviation of four eye movement parameters among four AOIs

Tasks	Visual	FC N=35	FD N=34	SA N=30	PS N=34
	RDP	46.74(25.036)	.269(.069)	55.461(30.958)	81.460(7.500)
	EFS	21.40(16.784)	.232(.060)	79.990(33.047)	77.062(10.441)
	TEL	13.74(14.189)	.293(.156)	62.759(38.502)	85.232(14.080)
	OTW	43.97(18.698)	.275(.075)	131.211(28.777)	79.572(8.189)

6.4.2 Findings of Large Scale Demonstration on Multiple Tower Operations

The concept of remote tower operations has been addressed as a suitable solution for enhanced cost efficiency and improved safety and is being developed in many countries. This research provided scientific evidence that multiple remote tower operations can achieve the objectives of Single European Sky ATM Research program. For the MRTO validation campaign, simultaneous landing and take-off at both airports are identified as traffic situations that should be examined further to explore the standards of safe operations and acceptable workload to ensure optimum ATCO task performance. During the trials no critical safety issues were identified by the team or other stakeholders such as pilots, or airport vehicles drivers. The trials provide one indication that multiple remote tower operations from an RTM can provide an acceptable level of safety (ALOS). A summary of operational results based on the 50 live exercises of multiple remote tower operations described as follows (table 6.6).

6.4.2.1 Batch-1 live trials

The first batch, exercises 1 to exercise 5, focus on Surface Movement Control which is the air traffic control service provided to aircraft, vehicles and personnel on the manoeuvring areas of Cork and Shannon airports excluding the runway in use. In certain cases, the SMC controller may provide an advisory service to aircraft on the aerodrome apron. The first batch of 5 exercises were to familiarise operational and technical personnel with procedures to be used for SMC. There were no safety occurrences in these 5 trials, however there are some human factors issues to be aware of, including (1) incorrect selection of a button on the COMPAD; (2) the Out of the Window view operated from a single shared mouse pointer which, from time to time, resulted in one Controller waiting for the other to manoeuvre the Zoom Camera; (3) in a local Tower environment the AMC and SMC can easily monitor each other's activities whereas in this exercise it was more difficult; (4) the working relationship between the SMC and AMC requires more intercom work. It is unlikely that in a future operation the AMC and SMC would be in a different location.

6.4.2.2 Batch-2 live trials

The second batch comprising exercises 6 to exercise 20 were to demonstrate the applicability of integrating both SMC and AMC with incrementally increasing traffic movements and mixing arrivals and departures at both Cork and Shannon airports. The suitability of the equipment has been assessed with a number of comments. During this phase the simultaneous scenario (Cork and Shannon) was introduced with low traffic movements. There were no safety occurrences in these 15 trials, however there are some potential risks to be aware of including (1) difficulty in seeing small aircraft and rapidly climbing aircraft; (2) increased workload as a result of increased simultaneous tasks; (3) the level of service is different to a local tower operation adding pressures to ATCOs; (4)

distractions due to multiple airports and multiple tasks; (5) quality of service might vary under operational conditions.

6.4.2.3 Batch-3 live trials

The third batch comprising exercise number 21 to exercise 50 built on the experience gained from previous exercises with increased traffic as appropriate in the sequenced and simultaneous scenarios. MRTO procedures in the previous batches were assessed with no additional procedure changes or amendments being required. However potential changes were discussed to operating methods in any future RTC environment such as better cooperation between airports involved in a Multiple Tower Operation whereby vehicle activity at each airport is coordinated so as to manage the workload of the MRTO controllers. Again, there were no safety occurrences in these 30 trials, however there are some potential risks to be aware of including (1) optimum traffic movements must be determined; (2) contingency plans for single ATCO performing multiple tower operations in the event of ATCO incapacitation for example; (3) set up of CWP in the RTC; (4) understanding the differences between ‘in sequence’ and ‘simultaneously’.

Table 6.6. Summary of operational exercises based on the 50 live exercises

Objectives of Exercises	Criteria	Results of Exercise
1 To evaluate the human performance related to Human-Computer Interaction (HCI) in a sequenced or simultaneous scenario.	Human performance and human factors have been measured and assessed for ‘in sequence’ and ‘simultaneous’ scenarios	There were two minor HF issues (1) The other minor issue was the Controller, on one occasion, made an incorrect selection of a button on the COMPAD; (2) The Mouse pointer in the Out of the Window view is a shared mouse pointer which, from time to time, resulted in one Controller waiting for the other to manoeuvre the Zoom Camera. However, with practice during the trials the Controllers became adept at co-ordinating the use of the mouse.

2	To identify shortcomings and limitations in order to identify corrective actions required before next batch of exercises	Any shortcomings and limitations have been identified and assessed and detailed for further examination.	In local Tower the AMC and SMC can easily monitor each other's activities whereas in this exercise it was more difficult. This presented a change in the working relationship between the SMC and AMC in terms of more intercom work was required. It is unlikely that in a future operation the AMC and SMC would be in a different location. However more evaluation would be required on this impact if this was to become the normal situation.
3	To demonstrate that the full range of ATS as provided from on-site control towers can be provided without degradation from the RTC	The tasks and duties of the ATCO providing services from the RTC have been measured and assessed in line with the developed procedures to ensure that there was no degradation of service when providing a service from the RTC.	As observed in the exercises 6 to 20 there are obvious differences between the Local Tower Operation and the RTC Operation. This mainly relates to the fact that the view from the Local Tower is better than the RTC. Some examples of this are: In exercise 10, the EFS is a fantastic tool with measurable safety benefits that the current paper strips don't provide. In exercise 15 there is a discussion about the difficulty in seeing smaller aircraft. In exercise 16 there is a discussion about rapid climbing aircraft. In exercise 17 there is a discussion about challenging lighting conditions.
4	To evaluate the human performance from the ATCO's and other human operators perspective in a sequenced or simultaneous scenario.	Human performance and human factors have been measured and assessed for 'in sequence' and 'simultaneous' scenarios related to attention distributions, situation awareness and perceived workload during performing multiple remote tower operations	Controllers are conscious of the fact that due to multiple tasks having to be done at the same time that the level of service is not the same as in the Local Tower and this adds to the pressure on the RTC ATCO. The main reason for this is that the Controller knows that if he was just performing a task for a single airport that e.g. this Vehicle would not have been delayed but because he was engaged in another task for the other airport he is delaying something in the other airport. This is alien to the Controllers because they would be used to very rarely having to delay replying to a Vehicle when Operating in the Local Tower.
5	To demonstrate the state of readiness of the remote tower initiative for industrialisation in the case of ATS provision for multiple airports	An assessment of the live trial demonstrations to support the proof of concept and readiness for industrialisation of remote towers for multiple airports has been conducted and assessed as positive.	The document "LSD 02 04 IAA Remote Tower System Operational Evaluation" (Annex 3 to this report) provides the project teams full assessment of the state of readiness of the systems provided for the provision of ATS provision for multiple airports. The document lists a number of suggestions for changes to systems which should be considered in advance of any potential future deployment.
6	To assess the demonstration exercises with respect to sequencing and metering to support 'in sequence' and 'simultaneous' operations.	The application of sequencing and metering processes as applied to two airports was measured and assessed.	As outlined in Batch 3 the project team have gained a very good understanding of what is possible in a Multiple airport 'in sequence' and 'simultaneous' aircraft operations. The new technology of PTZ, OTW and EFS did facilitate ATCOs task performance on multiple remote tower operations (exercises 46, 47, 48).

6.5 Discussion of Large Scale Demonstrations

The emergence of multiple remote tower operations is due in part to the changing operational environment in air transportation which has seen rapid expansion by low cost carriers at smaller airports. Cost constraints required ANSPs to develop new concepts and new technologies to fit the new business environment. The management of incoming and outgoing traffic at airports is a major function of ATCOs who follow procedures and guidance established by past practice, industry guidelines and regulatory policies. The operational procedures seek to ensure the safety while enabling efficiency operations (MacLean, Richman, & MacLean, 2016). The demonstration of 50 live trial exercises represented real-time, dynamic air traffic operations at both Cork and Shannon airports and demonstrated multiple remote tower operations led to no degradation of safety levels, no negative impact on capacity and human performance (European Aviation Safety Agency, 2015a; SESAR Joint Undertaking, 2013). Based on the results of these trials, the visual target tracking design of remote tower systems enables the automatic tracking moving objects such as vehicles/persons/animals on the manoeuvring area and aircraft in the air. This new technology has contributed to improved visual acquisition and has improved ATCOs' situational awareness.

6.5.1 Eye Scan Patterns of Single ATCO Performing Multiple Tasks

It was observed that depth perception was a potential issue (exercises 15, 16 & 17) in the RTC, as it was easier to judge the position of an aircraft in relation to another aircraft from the local tower than the RTC (Howard, 2012). When a single controller is responsible for four tower roles AMC/SMC in two airports, there is a requirement to actively use four frequencies in addition to monitoring two separate approach unit frequencies (for situational awareness). Consequently, there is an increased likelihood of the controller missing a transmission by an aircraft or vehicle (Bailey, Konstan, & Carlis, 2001). The organisation of the whole communications systems in the RTC needs to be explored further to ensure it is arranged so as to support effective HCI interaction with the other remote tower systems.

Visual presentation on the remote tower system in relation to the HCI functions shall not exceed the 1,000 millisecond of end-to-end delay in order to fit the requirements of safety assessment (European Aviation Safety Agency, 2015a). The results of eye tracking data analysis demonstrated the average fixation durations on OTW (275 ms), EFS (232 ms) and RDP (269 ms) for the scenario of aircraft in sequence departing and landing to Cork (table 6.5). The relationship of human information processing and complexity of operational tasks are related to the length of fixation duration (K. Rayner, 1998; Singh & Singh, 2012). The fixation duration is related to the amount of information processing (K. Rayner, 1998; Singh & Singh, 2012). When a single controller is managing two simultaneous arrivals into two different airports, EFS is the shortest fixation duration (232 ms), it may be the contribution of the comprehensive interface design. On the other side, the long fixation duration is on the TEL (293ms) which might be due to the complicated operational requirement to monitor so many radio frequencies at two airports. Furthermore, saccade is defined as fast eye movement between fixations and generally it declines as a function of increased mental workload (Ahlstrom & Friedman-Berg, 2006). The results reveal that saccade amplitude has significant interaction between AOIs and tasks performance. The TEL display consists of a screen with buttons and small digital numbers of radio frequencies used by all moving aircraft, vehicles and other parties on both Cork and Shannon airports. ATCO's must pay attention to select the correct frequency to communicate safely.

The view from the OTW displays objects at a smaller size compared to the object size when viewed from a traditional Tower, this results in it being difficult to see smaller objects far away from the camera. For areas of the airfield, such as runway incursion hotspots, further than 1.5KM from the cameras continuous use of the PTZ is required to get a clear view of the area. When two controllers were working in the RTC, as AMC or SMC controllers, at times both controllers required the use of the PTZ, due to current system design simultaneous interaction with another different PTZ was not possible and created a situation where one controller was not able to use PTZ in their particular area of interest. The interaction with PTZ and EFS (figure 6.6) is a new HCI issue which and might increase workload for ATCOs, this is an induced workload by MRTO technology which does not exist in traditional Towers to the same extent, i.e. PTZ is used more frequently than binoculars (Marchitto, Benedetto, Baccino, & Canas, 2016). In order to try to mitigate and reduce this workload in future MRTO, the IAA had discussed system revisions on PTZ manipulation with the supplier including: (1) Automatic PTZ tracking of certain Objects as determined by the controller; (2) Explore HMI adjustments to the PTZ manipulation; (3) Hotspot Cameras set up on targeted distant areas of the airfield displayed permanently on separate displays.

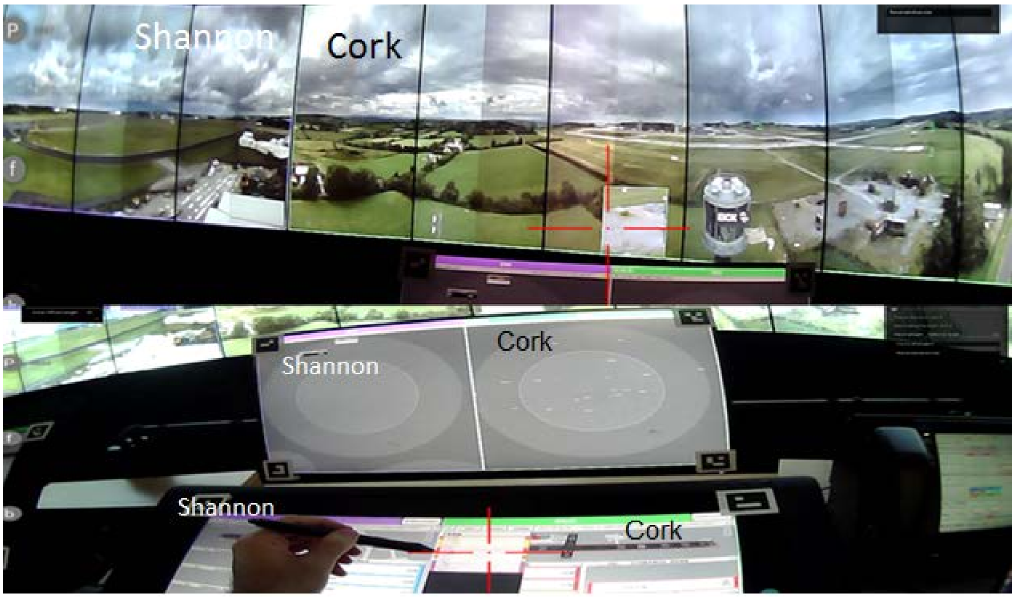

Figure 6.6. ATCO’s fixation duration on the EFS and OTW with PTZ recorded by Eye Tracker to investigate HCI functions and Human Performance on RTM

6.5.2 Impact on Safety

The certification of Innovative remote tower systems has to evaluate human information processing at initial operational stage to assure improved operators’ situation awareness, and safety (Satterfield et al., 2016). To conduct live exercises of multiple remote tower operations, the safety case must be approved by regulators. The IAA mandated a fundamental principle which required that MRTO operations must be at least as safe as the operations provided from a traditional tower. The safety case provided the evidence, arguments and assumptions to support this principle. During the trials the air traffic controllers and the RTC project team were governed by the same safety management policies, principles and procedures that exist in the Local Tower operations. Tower controllers are responsible for the safety and efficiency of the air movements and ground movements. Therefore, the monitoring of traffic within the control zone by ATCO’s visual attention resources is an important safety mechanism (Papenfuss & Friedrich, 2016). There were no safety occurrences during the 50 live exercises where there was a reduction in safety barriers which was not anticipated or provided for during the Safety Case development and update. When an AMC is managing two simultaneous arrivals into two different airports, ideally the first landing aircraft should be stable on the runway before the second arrival aircraft is 1NM from touchdown at the other aerodrome. However, OTW has the longest fixation duration for SMC due to the complexity of aircraft and vehicle movements. A Single ATCO performing simultaneous AMC and SMC functions is the biggest challenge within MRTO, as RDP and OTW show long fixation durations on multiple tasks.

To ensure the safety of operations by a single ATCO performing simultaneous departures at two different airports, it is suggested that additional time and distance between aircraft cleared for take-off and landing is implemented. This is because it is good practice that ATCOs monitor the critical phases of aircraft flight during initial roll and rotation and during the landing and rollout. There is a need to conduct further investigation of ATCO's visual attention related to situation awareness and HCI in the future. The project team concluded therefore that there was no adverse impact on safety while conducting the Remote Tower Trials from the RTC and conditions for the grant of project acceptance by the NSA were successfully maintained. The live trial exercises demonstrated that the ATS provided by the RTC for a single airport and two medium airports by a single controller with 'in sequence' and 'simultaneous' aircraft operation was at least as safe as the ATS provided by the Local Towers at both Cork and Shannon aerodromes. No safety occurrence was reported nor did any operational safety issue arise during the conduct of the fifty live trial exercises. Based on the live exercises as per the demonstration Plan, the objective of no degradation in safety levels between remote and local tower operations was achieved.

6.5.3 Impact on Capacity

In advance of commencing the Remote Tower trials, it was agreed that there would be little or no change to, or deviation from the air traffic services that the aircraft operators would normally experience when these services were provided from the Local Towers. In addition, when the RTC had control of the Shannon and Cork AMC positions, predicted traffic was constantly monitored to determine if and when the two AMC positions could be merged. On occasion when the two AMC positions were merged and controlled by a single controller it was necessary to ensure that ATCO didn't suffer from high workload and consequently impact safety and capacity. The control of a single Local Tower with both SMC and AMC positions from an RTC was applicable for the levels of traffic in the exercise scenarios. In advance of the positions being combined there were seven scheduled arrivals to the two airports in addition to a number of VFR aircraft. This situation initially increased ATCO's workload when operating AMC for two airports. Although the benefit of remote tower provision of ATC services for multiple remote towers was predicted to increase efficiency by 60% at some locations (Ziegler, 2016), it might have trade-off effects through increased ATCO's perceived workload when performing multiple tasks. Exercise-32 demonstrated that two 'in sequence' arrival flights into the two airports were manageable but it was noted that there was potential for delay at one airport due to activities at the other airport, particularly if that activities are unexpected or non-routine. The measurement of pupil dilation has been used to investigate the status of cognitive processes and mental workload, as pupil diameter increases as an indication of cognitive demand (Ahlstrom & Friedman-Berg, 2006). The results revealed that TEL is the highest pupil dilation (85.23 pixels), followed by RDP (81.46 pixels), OTW (79.57 pixels) and EFS (77.06 pixels). The controller managed his workload in the exercise and was able to prioritise which work had to be done and which work could wait while interacted with RTM (Kearney, Li, & Lin, 2016).

Operating innovative technology of RTM to maintain safe separation of aircraft both in the air and on the ground is not only an issue of technical skill performance but also of real-time decision-making involving situation awareness and risk management within a time-limited environment (Li, 2011). There may be a time lag based with MRTO compared to Local Tower operations, due to low cloud and moisture impacting the cameras and not impacting the Local Tower. For future application, workload resilience must be monitored to ensure that unplanned, unexpected aircraft such as Search and Rescue Helicopters can be accommodated without delay. Based on the exercises in the Demonstration Plan, there was no significant negative impact on capacity on multiple remote tower operations (table 6.7).

Table 6.7: The summary of Demonstration Plan of live exercises reflect to Capacity

Leading organisation	Irish Aviation Authority
Demonstration exercise objectives	The High level objective is to verify: • System Capability & Suitability • Operational CONOPS & Procedures Fine Tuning • Measurements for "In Sequence" Operations continue. • Initial measurements for "Simultaneous" Operations
High-level description of the Concept of Operations	These exercises will introduce aircraft in the air controlled by AMC at the RTC for the two airports. The AMC will be done by the RTC for both airports. The SMC will control the ground traffic at both airports.
Applicable Operational Context	• Cork & Shannon airport • All SMC (Surface Movements OPS) • All Aircraft controlled by AMC at the RTC for both airports in light traffic i.e. <3 aircraft for both airports. • Perform initial analysis on other influencing factors such as Daylight & poor weather conditions.
Impact on Capacity	Capacity: No negative impact on Capacity or traffic that can be handled in this mode. Cost efficiency: Document initial results for a single ATCO performing the task which today is performed by two ATCOs

6.5.4 Impact on Human Performance

Air traffic control is a complex cognitive task, it involves perceived information, processing information and decision-making (Papenfuss & Friedrich, 2016). During the trials a number of human factor issues were encountered, most of which were anticipated (e.g. the operation of new equipment and associated HCI) and some which were not anticipated such as the level of noise in the RTC when a single controller was operating four frequencies and monitoring an additional two frequencies. Multiple Remote Tower Operations might be a good solution for increasing safety and capacity at small/medium airports as there was a trend of increased ATCO's performance however with aby-product of increased workload compared to traditional tower operations. Current research supports previous findings that ATCO's mental effort increased and detection performance deteriorated with the numbers of controlled airports (Oehme, Leitner & Wittbrodt, 2013). There is a requirement to address the issue of controllers' perceived workload while performing MRTO either by training, additional staffing or designing new standard operating procedures or interface design (European Aviation Safety Agency, 2015c; SESAR Joint Undertaking, 2013, 2015b), as workload can negatively affect a controller's situation awareness and increase the potential for error. However, suitable human-cantered design RTM including OTW, EFS & PTZ systems can significantly improve controllers' situation awareness and reduce their cognitive workload (Laois & Giannacourou, 1995; Tobaruela et al., 2014), and increase their capability to process the information (Wickens, Miller, & Tham, 1996). Ideally the first landing aircraft should be steady on the Runway before the second arrival aircraft is 1NM from touchdown at the other aerodrome in Multiple Airport Simultaneous Operations (MASO). It was noted that meeting this guideline may be difficult when controlling aircraft of varying approach speeds. Recommendation in this area in the future may be supported by an additional caveat which would give the controller the authority to exercise professional judgement with regard to the issuance of a landing clearance to the second arriving aircraft. Previous research had demonstrated that significant benefits were achievable by the field trials (Simaiakis et al., 2014).

ATCO's visual behaviours provide an opportunity to investigate the relationship between eye movement patterns and task performance. Eye scan pattern is one of the most powerful methods for assessing human beings' cognitive processes (Ahlstrom & Friedman-Berg, 2006). The air traffic flows of Cork and Shannon were combined in a data set describing traffic situation, consisting of time, type of event and time distance. Only data sets with time distances less than 60 seconds were regarded as valid 'simultaneous' conditions. Whilst the landing is represented in the flight movement data by a single timestamp, the actual process of landing occupies the ATCO's attention longer by monitoring closely the final approach until the aircraft touches down and stabilises on the runway. Therefore, two aircraft landing within the 60 second time span can be considered as simultaneous in respect of the monitoring task of the controller (Schier et al., 2011). Based on the exercises in the Demonstration Plan, there was no negative impact on human performance during multiple remote tower operations.

6.6. Conclusion and Recommendation

The implementation of multiple remote tower operations is promising as new technologies can enhance ATCO situation awareness. The findings are valuable for both ATCO training and system design. In terms of standardisation, the results of the 50 live demonstrations can provide feedback to EUROCAE WG-100 "Remote and Virtual Towers" (EUROCAE, 2016) in developing standards for both single and multiple modes of remote towers systems for adoption by ICAO as standards and recommended practices. There were no safety occurrence reports nor did any operational safety issue arise during the conduct of the fifty live trial exercises. However, there are some issues to be aware of for future implementation, including the impact of monitoring different radio frequencies and perceived workload. Workload management in the provision of ATS for multiple towers is a new challenge for air traffic controllers, and practice is required to balance the workload by distributing tasks more evenly where possible. Multiple remote tower operations show potential as an alternative to traditional Local Towers. The novelty and flexibility of the advanced technology allows regulators to be creative in adapting operations to fit safety regulations, it also has the potential to fundamentally change the way operators provide ATS. From a regulatory perspective the results of these live trials may contribute to EASA rulemaking activity for single and multiple airports remote tower operations.

CHAPTER VII

General Discussions

7.1 Overview

The development of advanced technology in the aviation industry has significantly changed the traditional air traffic management (ATM) system and air traffic controllers' (ATCO) task performance. In Europe, the Single European Sky initiative has been set up to improve safety, minimise costs and environmental impact, and at the same time increase efficiency and capacity in order to meet the requirements of increasing air traffic (Eurocontrol, 2014). The COOPANS Alliance has demonstrated leadership among air navigation service providers by deploying an advanced ATC system, among it partners and ensuring it meets EU Implementing Rules on time. Furthermore, the innovative concept of multiple remote tower operations (MRTO) can maximise cost savings by applying video panorama-based remote tower working positions, which permit less air traffic controllers to fulfil the Air Traffic Management tasks for controlling air movements and ground movements at more than one airport safely.

The aim of this research is to develop effective Human-centred designs in modern ATM systems to permit Air Navigation Services Providers achieve the aims of EU Single European Sky and be more effective in their air traffic controller deployment and training Therefore, this research consists of two projects, the first project is the evaluation of human-computer interactions on the COOPANS Air Traffic Management system which has been described in chapter two: the impact of alerting design on air traffic controllers' response to conflict detection and resolution, and chapter three: application of semantic design to support air traffic controllers' situation awareness to short term conflict alert; and the second project is the evaluation and certification of multiple remote tower operations which has been described in chapter four: how much is too much? visual scan patterns of single air traffic controller performing multiple remote tower operations, chapter five: applying human error identification method to evaluate single air traffic controller conducting multiple remote tower operations, and chapter six: multiple remote tower for single European sky: the evolution from initial operational concept to regulatory approved implementation.

7.2 Alerting Design Impacting Conflict Detection and Resolution

The COOPANS Air Traffic Management (ATM) System provides three kinds of alerts which are designed to alert controllers to three distinct critical risks, Short Term Conflict Alert (STCA), Minimum Safe Altitude Warning (MSAW), and Area Proximity Warning (APW). Activation of any of these three alerts by acoustic alert indicates a potential conflict between aircraft, conflict between aircraft and prohibited airspace and conflict between aircraft and terrain, therefore the air traffic controller is expected to respond and resolve the potential conflict as fast as possible to ensure the safety of the aircraft. The COOPANS system is deployed in five countries within Europe, Ireland, Denmark, Sweden, Austria and Croatia, and the air traffic controllers (ATCO's) within these five countries all operate a harmonised system which provides three critical alerts using the same audio alerting schema. Furthermore, the COOPANS system is seen as a major step in achieving the European Union aspiration of harmonised ATM systems across Europe in support of Single European Sky. The COOPANS system has a potential design issue which is an alert activation for STCA, MSAW or APW might be misinterpreted as the acoustic signal for all three alerts is the same sound (Beep-Beep-Beep-Beep). This has the potential to induce ATCO's into misjudging the type of critical alert being presented and therefore the ATCO's resolution response may be incorrect for the critical situation being signalled or worse as a result of startle effect the ATCO may suffer a delayed response to the critical situation or simply silence the acoustic alert, any of these responses not resolving the critical situation occurring and thereby weakening system safety.

In study-1, the research aim is to develop a better auditory alert for the COOPANS ATM system that can improve air traffic controllers' situation awareness, response and improve aviation safety as a result. Participants included seventy-seven qualified Air Traffic Controllers. The experiment was conducted in the Air Traffic Control operational rooms of the Irish Aviation Authority at Shannon and Dublin. Participants were advised that the trials were in relation to the COOPANS Air Traffic Control. There is a significant difference in ATCO's response time between acoustic alert and semantic alert across STCA, APW and MSAW. The results demonstrated that the acoustic alert deployed within the COOPANS ATM system provides level-1 Situational Awareness to ATCO's compared with a semantic alert which provides not only level-1 situational awareness for alerts, but also level-2 and level-3 situational awareness to assist ATCO's understanding the critical event occurring and consequently developing more suitable solutions. Consequently, a human-centred designed semantic alert significantly improved the speed of ATCO's response to STCA, and APW.

The sematic alert alleviated expertise differences by promoting quicker response times for both novice and experienced air traffic controllers. This represents significant benefit to the air navigation service provider as it permits reduced training costs as separate training courses for novices and experts are not required. Improved ATCO situational awareness and faster more accurate ATCO responses to critical situations also means that ATCO's can return to normal sector operations faster following a critical event thereby also contributing to improved ATCO productivity. Initial estimates put this productivity improvement at 1% annually. This represents a saving of €2,728,337 per annum across all five COOPANS Air Navigation Service Provider's or €13,641,685 over EU SES RPII (Eurocontrol ACE, 2013). The fact that the critical situations are being resolved more safely and efficiently means that ATCO can resume normal operations within the rest of the air traffic control sector sooner permitting an overall improvement in sector capacity volumes. Civil Aviation Authorities, Air Navigation Service Providers and Air Traffic Management system providers may derive benefits form this research by adopting the principles within their own ATM systems to ensure optimal alerting schemes for their air traffic controllers. Furthermore, the various airline representative bodies may capitalise on this research by encouraging the EU and the European Aviation Safety Agency to develop regulations governing the design of ATM system alert systems to ensure enhanced situational awareness and improved safety for their aircraft operations, crews and passengers.

7.3 ATCO's Visual Behaviours and Situation Awareness

ATCOs' visual search for maintaining SA is affected by the surrounding environment and the interface designs on the ATM system they use. The factors manipulating visual attention include how information is presented, the complexity of the interface design, and the operating environment. The results of this research revealed no difference on fixation counts before-alert activation between acoustic and semantic design. Interestingly, the semantic design increased significantly the fixation counts compared with the acoustic design after alert activation. Furthermore, there is no difference of fixation duration before alert activation between acoustic and semantic design. However, the semantic design increased significantly the fixation duration compared to the acoustic design after alert activation. This implies that the semantic design promotes ATCO's SA through increased fixation numbers, allowing the ATCO to collect more information on the critical event occurring, and to conduct deliberate cognitive thinking through cumulative fixation duration which is related to problem-solving and therefore to developing better conflict resolution strategies.

It is reasonable that there are no significant differences between acoustic design and semantic design before alert activation, as an ATCO's cognitive processes are only triggered by the activation of alerts. The results of this research support previous findings that fixation duration reflects the concentration degree in extracting information, and fixation numbers reveal that critical information is processed by ATCO's to gain SA (Kotval & Goldberg, 1998). ATCOs established different eye movement patterns on fixations number, fixation duration and saccade velocity. Effective decision support systems require human-centred design with effective stimuli to direct ATCO's attention to critical events. Once you direct the ATCO to the critical event it is necessary to provide ATCOs with specific alerting information to reflect the nature of the critical situation in order to minimise the side-effects of startle and inattentional deafness and to promote enhanced resolution strategies. Consequently, the design of a semantic alert can significantly reduce ATCOs' response time, providing valuable extra time in a time-limited situation to formulate and execute resolution strategies for critical air safety events.

The design of decision support systems for use in dynamic environments must efficiently integrate with the characteristics of human cognitive processing. It is necessary to provide air traffic controllers with context-specific semantic stimuli which provide definitive information to reflect the nature of the critical situation in order to minimise the side-effect of startle. The results of this research demonstrate that semantic alerts provide not only level-1 SA, but also promote level-2 SA in assisting ATCOs understand the nature of the critical event permitting quicker development of strategies for conflict resolution. The findings of this research indicate that the context-specified design of semantic alerts could improve ATCO's situational awareness and significantly reduce response time to perform conflict resolution. Resolving critical situations more effectively means not only is aviation safety improved by ATCOs can resume normal operations within the rest of the sector sooner minimising the overall impact to other aircraft and the air traffic system generally. Civil Aviation Authorities, Air Navigation Service Providers and Air Traffic Management System Providers could all benefit from the findings of this research with a view to ensuring that Air Traffic Controllers are provided with the optimal context-specified alerting schemes to increase their situational awareness to handle unforeseen critical events. Improving air traffic controller response to critical events in ever crowded European skies presents the European Aviation Safety agency with an opportunity to further improve air navigation service provider safety performance. The development of a European standard for ATM system critical situation alerts should be a prime focus of the European Aviation Safety Agency.

7.4 Visual Scan Pattern on Multiple Remote Tower Operations

The initial concept of remote tower operation (RTO) was for air traffic services (ATS) to be delivered remotely without direct observation from a local tower. Based on the concept of remote tower operations, multiple remote tower operations (MRTO) offers further opportunity for cost efficiency in the provision of air traffic services for small and medium sized airports, especially if a single controller could provide air traffic services to two (or more airports) at the same time. Remote tower technology allows one air traffic controller (ATCO) to control one or more airports at the same time, a significant consideration of course is what an appropriate traffic volume for a single air traffic controller to manage might be. The innovative concept of multiple remote tower operation (MRTO) is where a single air traffic controller (ATCO) provides air traffic services to two or more different airports from a geographically separated virtual Tower. Effective visual scanning by the air traffic controller is the main safety concern for a single controller performing MRTO, in an environment where, they are managing tasks previously managed by up to four air traffic controllers, notwithstanding the additional support of new technology.

The results of this research demonstrated that ATCOs' visual scan patterns showed significant task related variation while performing different roles and interacting with the various interfaces on the controller's working position (CWP). ATCOs worked with innovative technology and display systems with outside views provided by PTZ camera whilst performing multiple remote tower operations. This research indicates that increased pupil dilation and decreased saccade amplitude in a visual search task are related to strategic adaption to the demands of the tasks for a single ATCO to perform MRTO. Visual activity is the objective method for assessing an ATCO's cognitive process related to real-time decision-making (Ayaz et al., 2010). The concurrence of excessive fixations, long fixation duration and less saccade duration is the precursor of tunnelled attention (Johnson & Proctor, 2004). ATCO's visual behaviours provide an opportunity to investigate the relationship between eye movement patterns and information processing. Eye scan pattern is one of the most powerful methods for assessing human beings' cognitive processes in Human–Computer Interaction. For example, saccade is defined as fast eye movement between fixations and generally it declines as a function of increased mental workload (Ahlstrom & Friedman-Berg, 2006).

The distribution of visual attention among display systems is the key human-computer interaction issue in single ATCOs performing multiple monitoring tasks. Information presentation on the remote tower module and information interpretation by the ATCO are crucial elements in assuring aviation safety and optimal human performance. Current OTW and EFS on the RTM demonstrate that effective human-centred design in relation to information presentation can simplify ATCOs' cognitive processes by reducing the volume of visual searching thereby alleviating cognitive load. Furthermore, innovative remote tower technology will facilitate staffing and equipment cost-efficiencies including Communications, Navigation, Surveillance and Flight Data Processing Systems. There is potential to save approximately €2.21 million Euro per annum per installation. ATCO's visual attention and monitoring performance can be affected by how information is presented, the complexity of the information presented, and the operating environment in the remote tower centre. To achieve resource-efficient and sustainable air navigation services, there is a real need to improve the design of human-computer interactions in multiple remote tower technology deployment and development. These must align with high technology-readiness level, operators' practices, industrial developments, and the certification processes of regulators.

The use of eye tracking data to gain insight into the cognitive performance of air traffic controllers is a specialised way of providing objective assurance to regulators by air navigation service providers that system or procedure enhancements are safe for service. Eurocontrol should ensure that eye tracking data can be provided to air navigation service providers as part of the Eurocontrol research facility at Bretigny, France, when simulating large scale system, airspace and procedural changes. Furthermore, Eurocontrol should take the lead in providing eye tracking equipment and analysis capabilities to air navigation service providers to integrate this objective means of human performance analysis into routine system evolutions.

7.5 Increasing Human Performance Also Increasing Workload

Air traffic activities are constantly evolving with different traffic types, traffic volumes and weather changes. Therefore, ATCO's have to deal with more and more information that could cause a significant increase in their workload. Appropriate interface design in ATM systems can discharge ATCO cognitive loads and enhance SA by facilitating a better match between task demands and cognitive resource (Kaber, Perry, Segall, Mcclernon, & Iii, 2006). Effective coordination of human-computer interaction is crucial to the successful implementation of innovative systems in the MRTO environment. Interface design must apply holistic approaches to facilitate distributed cognition coordination in rapidly changing situations (Langan-Fox, Canty, & Sankey, 2009), as high performance in conflict detection and resolution has the potential to increase both airspace efficiency and the safety of aviation (Schuster & Ochieng, 2014). ATCOs' task performance and perceived workload might increase if technologies require operators to process more information and monitor more targets on interface displays. Increased cognitive workloads increase the risk of inattentional tunnelling, cognitive lockup, and out-of-the-loop syndrome (Endsley & Kiris, 1995). One of the most commonly used measures of operator's perceived workload is NASA Task Load Index (Hart & Staveland, 1988). Workload can negatively affect ATCOs' performance and increase operational errors (Athènes, Averty, Puechmorel, Delahaye, & Collet, 2002). Wickens (2002) defines workload as the load imposed on the limited information processing resources of the unaided (without assistance of automation) human operator described as the "baseline" or "manual" condition. Task management is directly related to mental workload, as the competing demands of tasks for attention exceed the operator's limited resources, and better multitask performance results from rapid switching between tasks (Wickens, 1999).

This research demonstrated the concept of MRTO is applicable to provide both air and ground movement controls for two low volume airports by one ATCO. However, how much is too much when it comes to tasks for a single controller? MRTO is safe whilst operations are routine, the evolution of a critical event at one or two airports has the potential to overload the single ATCO, this requires additional study and analysis before MRTO operations can be deployed (Kearney & Li, 2018). The development of new remote tower technology is designed to reduce ATCO's workload through augmented vision presented on OTW, RDP and EFS. However, the added complexity of multiple tasks did create more cognitive loads to ATCOs to process huge volumes of information (Wiener, 1988; Li, Kearney, Braithwaite, & Lin, 2018). Augmented visualisation design of RTM allows ATCOs to change the size of the screen for selected airports, this innovative technology has significantly increased ATCO's task performance. However, there are also some potential risks related to HCI and human performance and this requires further research to precisely identify these impacts and suggest suitable mitigation strategies to defend against the risks (Ltifi, Kolski, & Ayed, 2015).

The application of remote tower technologies can assist ANSP's achieve cost efficiency and safety requirements as mandated through the EU Single European Sky project. This research demonstrated that augmented visualisation using panorama video cameras did provide sufficient technical support for a single ATCO to perform tasks initially planned to be achieved by four ATCOs, however, the demands of multiple tasks also induced significant workload. It must be stated that this research is based on normal operations and does not consider the impact of an unusual situation, critical event or emergency during the operation. Should an unexpected event occur, it is reasonable to expect that workload will likely increase thus having the potential to negatively impact on ATCO's performance. This creates a need for further research on how to relieve ATCO's workload. MRTO has been proven as safe as the local tower operation in providing air traffic services. The novelty and flexibility of remote tower technology may allow regulators to be creative in adapting safety regulations and ANSP's to be more operationally agile in the management of varying traffic volumes. Nevertheless, the evolution and deployment of MRTO systems requires a cautious balance between cost-efficiency and the potential impacts on safety, capacity, and human performance.

The European Aviation Safety Agency should establish a research call to specifically assess the human performance implications of MRTO operations during unusual circumstances such as system degradations, aircraft technical issues, emergencies and unusual situations and to make recommendations for system designs to improve air traffic controller performance in MRTO in unusual circumstances.

7.6 Certification of Multiple Remote Tower for Single European Sky

The European Union project, Single European Sky, initiated a reorganisation of European airspace and proposed additional measures for air traffic management to achieve the key objectives of improving efficiency and capacity while at the same time enhancing safety. The motivations of this research are to understand the limitations of controlling simultaneous traffic patterns at two airports by a single ATCO, to demonstrate how the implementation of the advanced technology impacts safety, capacity and human performance, and how to conduct safety assessment of MRTO in order to secure regulatory approval for live operations. Based on the concept of remote tower operations, multiple remote tower operations (MRTO) offer further solutions for cost efficiency of air traffic services for small and medium size of airports. The new technology will allow one air traffic controller (ATCO) control two or more airports at the same time during low traffic volumes. The control of multiple airfields can be centralised to a virtual centre permitting the more efficient use of ATCO resources. This research was sponsored by the Single European Sky ATM Research Program and the ATM Operations Division of the Irish Aviation Authority. A safety case was developed for migration of multiple remote tower services to live operations.

This research conducted 50 large scale demonstration trials of remote tower operations from single tower operations to multiple tower operations for safety assessment by air navigation safety regulators in 2016. A dedicated team of air traffic controllers and technology experts successfully completed the safety assessment of multiple remote tower operations in real time. The air movement control and surface movement control at both Shannon and Cork airports were conducted simultaneously from a virtual remote tower centre at Dublin Airport, Ireland. The implementation of this innovative technology requires a careful balance between cost-efficiency and the safety of the air traffic control services in terms of capacity and human performance. The live trial exercises demonstrated that the air traffic services provided by the remote tower for a single airport and two medium airports by a single ATCO with ‘in sequence’ and ‘simultaneous’ aircraft operations was at least as safe as provided by the local towers at Cork and Shannon aerodromes. There were no safety occurrence reports nor did any operational safety issue arise during the conduct of the fifty live trial exercises. However, there are some issues to be aware of for future implementation, including the impact of monitoring multiple different radio frequencies and perceived workload. Workload management in the provision of ATS for multiple towers is a new challenge for air traffic controllers, and practice is required to balance the workload by distributing tasks more evenly where possible. Multiple remote tower operations show potential as an alternative to traditional Local Towers. The novelty and flexibility of the advanced technology allows regulators to be creative in adapting regulations to take account of new operational practices, it also has the potential to fundamentally change the way operators provide ATS. From a regulatory perspective the results of these live trials may contribute to EASA rulemaking activity for single and multiple airports remote tower operations.

CHAPTER VIII

Conclusion and Future Works

8.1 Conclusion

Achieving effective human performance during multiple remote tower operations requires a strategic, collaborative and automated concept of operations to increase capacity and safety (Schuster & Ochieng, 2014). The application of this research's findings could not only reduce ATCO's training cost for Air Navigation Service Providers, but could contribute to more effective air traffic management system design by Air Traffic Management System suppliers through the deployment of the most optimal alerting schemes to increase Air Traffic Controllers situational awareness and performance thereby improving aviation safety. The results demonstrate that human-centered design and augmented visualisation provided sufficient technical supports to enhance ATCOs' task performance to the extent that a single ATCO successfully performed Air Traffic Control tasks originally designed to be performed by four ATCOs. However, despite the additional system supports and the improved operational design, the task demands did induce increased perceived workload. It must also be noted that this research is based on a normal operating environment and so did not consider the impact of an unusual situation or critical event or emergency during the operation. Should an unexpected event occur workload may snowball thus having a negative impact on ATCO's performance through increased time pressure and cognitive process pressure required to manage the operation and deal with the unusual event. This creates a need for further research on how to relieve this additional perceived workload and fatigue to ensure that Air Traffic Controllers have the capacity to manage normal operations and sufficient spare capacity to manage any unusual events which may occur.

The evolution of and deployment of new enhanced ATM technologies is foreseen by Air Navigation Service Providers as a panacea to enhanced capacity, improved safety and ATCO and cost efficiency. A failure to adequately assess these new technologies and tools within the home environment prior to deployment raises the potential for unintended consequences which may impact on efficiency and safety. Human-centered design in ATM systems and on deployment offers systems manufacturers and Air Navigation Providers greater assurance of efficient and successful operational system deployment, it also makes user acceptance more likely thereby ensuring the expected improvements in terms of safety efficiency and capacity are achieved. The concept of remote tower operations has been addressed as a suitable solution and continues to be developed in several countries. This research provided scientific evidence that multiple remote tower operations can achieve the objectives of Single European Sky ATM Research program. The findings can be applied to both ATCO training and system design for certification. In terms of standardisation, the results of the live demonstrations can provide feedback to EUROCAE WG-100 "Remote and Virtual Towers in developing standards for both single and multiple modes of remote tower systems for adoption by ICAO as standards and recommended practices. Furthermore, the research findings confirmed that the concept of human-centered design provided the potential for more cost-efficient deployment of human resources to air navigation service providers, particularly when combined with other initiatives such as the centralisation of Approach Control Services and for contingency purposes. The novelty and flexibility of advanced technology permits regulators to be creative in adapting safety regulations to new operational practices and provides Air Navigation Service Providers to radically change the how they provide their services.

8.2 Recommendations to Future Works

Based on the findings of this series of research there are several recommendations to air navigation service providers, manufacturers, and regulators as follows:

1. Human-centered design should be able to provide effective information which facilitates the ATCO’s attention being alerted without startle; it should further support ATCO’s decision-making to solve the problems more efficiently. The design of automated aids must facilitate ATCO’s performance with timelier alerting to enhance perception and enable precise comprehension of visual and auditory information. The principle of human information processing can be applied to improve the alerting design of the COOPANS Air Traffic Management system, and to design multiple remote tower operations to increase ATCO’s situation awareness.

2. A semantic alert which not only provides level-1 of SA (perception of the alert), but also level-2 of SA assisting the ATCO in understanding the nature of the critical event permits more rapid solution development. The design of semantic alerting in the COOPANS Air Traffic Management system has the potential to improve ATCO’s response times to critical situations, providing more time for solution generation and improving the likelihood that the most appropriate resolution strategy will be deployed.

3. Appropriate ATM system alerting design could alleviate the expertise differences between novice and expert ATCO’s by promoting quicker response time to critical events regardless of level of expertise. Therefore, a single training program could be deployed for both novice and expert ATCO’s, thereby providing training cost advantages to Air Navigation Service Providers, and ensuring that novices and experts both have enhanced situational awareness and reduced response times to

critical events. This represents significant benefit to the air navigation service provider to reduce training cost and to increase safety of air traffic management.

4. The distribution of visual attention among display systems is the key human-computer interaction issue for single ATCO's performing multiple monitoring tasks. Information presentation on the remote tower module and information interpretation by the ATCO's are crucial elements in assuring aviation safety and optimal human performance. Current OTW and EFS on the RTM demonstrate that effective human-centred design in relation to information presentation can simplify ATCOs' cognitive processes by reducing the volume of visual searching thereby alleviating cognitive load.

5. ATCO's visual behaviours provide an opportunity to investigate the relationship between eye movement patterns and task performance. Eye scan pattern analysis is one of the most powerful methods for assessing human beings' cognitive processes and perceived workload.

6. There were no safety occurrence reports nor did any operational safety issue arise during the execution of the fifty live trial exercises. However, there are some issues to be aware of for future implementation, including the impact of monitoring different radio frequencies and increased perceived workload. Workload management in the provision of ATS for multiple towers is a new challenge for air traffic controllers, and practice is required to balance the workload by distributing tasks more evenly where possible. Multiple remote tower operations show potential as an alternative to traditional Local Towers.

7. The novelty and flexibility of the advanced technology allows regulators to be creative in adapting safety regulations to different operational methodologies, it also

has the potential to fundamentally change the way operators provide ATS. From a regulatory perspective the results of these live trials can contribute to EASA rulemaking activity for single and multiple airports remote tower operations.

8. Air Navigation Service Providers should adequately invest in human performance analysis of new systems prior to their deployment. This provides the opportunity to identify any local conditions which may compromise the system capability and offer the opportunity to create mitigation strategies to ensure that the new technology benefits are achieved.

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Appendix. Human Error Template Evaluation for Multiple Remote Tower Operations

Human Error Template (HET) is a newly developed HEI methodology, aimed specifically at predicting human performance on Human-Computer Interaction in aviation (Stanton et al, 2009). The method is a checklist approach and comes in the form of an error template. HET works as a simple checklist and is applied to each bottom level task step in a hierarchical task analysis (HTA) of the task under analysis. HTA is a means of describing a system in term of a structured hierarchy of goals and sub-goals with feedback loops (Annett, 2005). It is inherently flexible and the approach can be used to describe any system. The HET technique works by indicating which of the HET error modes are credible for each task step, based upon the judgment of the analyst. The analyst simply applies each of the HET error modes to the task step in question and determines whether any of the modes produce any credible errors or not. The HET error taxonomy consists of twelve error modes that were selected based upon a study of actual human error incidence and existing error modes used in contemporary HEI methods in aviation domain. The twelve HET error modes are shown below:

Scenario: Simultaneously Landing on EICK & EINN			Task step: 1.1.1 Answer phone (10-15 s)								
Error mode	Tick	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
CAUTION to execute	V	ATCO not able to answer the phone due to workload	Lack of coordination and information deficit			V			V	V	
Task execution incomplete	V	Message not fully received	Incomplete information			V			V	V	
Task executed in wrong direction	V	Failure to identify the correct source	Momentary confusion			V			V	V	
Wrong task executed	V	Call-sign/SSR confusion	Incorrect coupling		V				V	V	
Task repeated	V	Coordination repeated	Distraction and time consuming might increase workload			V			V	V	
Task executed on wrong interface element											
Task executed too early											
Task executed too late	V	ATCO not able to answer the phone in time due to workload	Lack of coordination and time consuming		V				V	V	
Task executed too much											
Task executed too little											
Misread information	V	Miss interpretation of runway information	Wrong runway selection			V		V		V	
Other											

HTA of Simultaneously Landing on EINN and Departing EICK

1.1 Co-ordination call from EINN APP
- 1.1.1 Answer phone (10-15 s)
- 1.1.2 Record transponder code (5 s)
- 1.1.3 Make cross check on EICK (2 s)
- 1.1.4 Insert strip into ARR sequence (3 s)

1.2 Co-ordination call from EICK APP
- 1.2.1 Answer phone (10-15 s)
- 1.2.2 Record transponder code (5 s)
- 1.2.3 Make cross check on EINN (2 s)
- 1.2.4 Insert strip into ARR sequence (3 s)

1.3 First contact from EINN Arrival
- 1.3.1 Acknowledge call + reply (8 s)
- 1.3.2 Assume FLT strip for A/C (2 s)
- 1.3.3 Cross check EICK (2 s)
- 1.3.4 Cross check position on RDP (2 s)
- 1.3.5 Utilize OTW picture to identify A/C on approach (3 s)
- 1.3.6 Scan predicted A/C track using OTW (3 s)

1.4 First contact from EICK Arrival
- 1.4.1 Acknowledge call + reply (8 s)
- 1.4.2 Assume FLT strip for A/C (2 s)
- 1.4.3 Cross check EINN (2 s)
- 1.4.4 Cross check position on DFTI (2 s)
- 1.4.5 Utilize OTW picture to identify A/C on approach (3 s)
- 1.4.6 Scan predicted A/C track using OTW (3 s)

1.5 Landing clearance issuance EINN
- 1.5.1 Scan runway for obstruction (15 s)
- 1.5.2 Transmit landing clearance (8 s)
- 1.5.3 Record clearance to land on EFS (2 s)
- 1.5.4 Cross check EICK (2 s)

1.6 Landing clearance issuance EICK
- 1.6.1 Scan runway for obstruction (15 s)
- 1.6.2 Transmit landing clearance (8 s)
- 1.6.3 Record clearance to land on EFS (2 s)
- 1.6.4 Cross check EINN (2 s)

1.7 Monitoring A/C landing EINN

1.7.1 Scan runway (10 s)
1.7.2 Scan anemometer issue surface wind vector (3 s)
1.7.3 Cross check EICK (2 s)
1.7.4 Scan runway (6 s)
1.7.5 Monitor A/C touchdown + roll (10-15 s)
1.8 Monitoring A/C landing EICK
1.8.1 Scan runway (10 s)
1.8.2 Scan anemometer issue surface wind vector (3 s)
1.8.3 Cross check EINN (2 s)
1.8.4 Scan runway (6 s)
1.8.5 Monitor A/C touchdown + roll (10-15 s)
1.9 Vacate Runway EINN
1.9.1 Issue runway exit + taxi route (8 s)
1.9.2 Cross check EICK (2 s)
1.9.3 Confirm runway vacated (2 s)
1.9.4 Record vacated on strip (2 s)
1.10 Vacate Runway EICK
1.10.1 Issue runway exit + taxi route (8 s)
1.10.2 Cross check EINN (2 s)
1.10.3 Confirm runway vacated (2 s)
1.10.4 Record vacated on strip (2 s)
1.11 Taxi instruction to stand EINN
1.11.1 Check stand (2 s)
1.11.2 Issue taxi route (6 s)
1.11.3 Cross check EICK (2 s)
1.11.4 Record parked (2 s)
1.12 Taxi instruction to stand EICK
1.12.1 Check stand (2 s)
1.12.2 Issue taxi route (6 s)
1.12.3 Cross check EINN (2 s)
1.12.4 Record parked (2 s)
(Terminated)

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.2.1 Check apron on OTW (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not check the Apron in EICK.	Lack of situational awareness potentially leading to an incorrect push back clearance.			V		V		V	
Task execution incomplete	V	ATCO only checks EICK Apron partially.	Lack of situational awareness potentially leading to an incorrect push back clearance.			V		V		V	
Task executed in wrong direction	V	ATCO checks Shannon Apron thinking is EICK Apron.	Lack of situational awareness potentially leading to an incorrect push back clearance.			V		V		V	
Wrong task executed	V	ATCO performs other tasks when he meant to check the apron	Lack of situational awareness potentially leading to an incorrect push back clearance.			V		V		V	
Task repeated	V	ATCO repeatedly checks the Apron in EICK .	ATCO loses time to perform other tasks.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO checks the Apron well in advance a push back clearance is issued.	Potential lack of new elements not being considered possibly leading to an incorrect push back clearance.			V		V		V	
Task executed too late	V	ATCO checks the Apron after push back clearance is been issued.	Potentially incorrect push back clearance.			V		V		V	
Task executed too much	V	ATCO spends too much time checking the Apron in EICK.	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	ATCO only checks Cork Apron partially or not thoroughly.	Lack of situational awareness potentially leading to an incorrect push back clearance.		V			V		V	
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.2.2 Issuance of push back clearance (5 s)										
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not issue a push back clearance.	a/c is delayed on stand.		V				V	V	
Task execution incomplete	V	ATCO does not issue a full push back clearance.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction	V	ATCO issues a push back clearance to the landing aircraft.	Possible confirmation sought from the pilot on the ground.			V			V	V	
Wrong task executed	V	ATCO performs other tasks when he meant to issue a push back clearance.	a/c is delayed on stand.			V			V	V	
Task repeated	V	ATCO issues a push back clearance two or several times.	Increased workload leading to a loss of time to perform other tasks.		V				V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues a push back clearance too early.	Possible confirmation sought from the pilot on the ground. ATCO loses time to perform other tasks.			V			V	V	
Task executed too late	V	ATCO issues a push back clearance too late.	Possible multiple requests sought from the pilot on the ground. ATCO loses time to perform other tasks.			V			V	V	
Task executed too much	V	ATCO spends too much time issuing a push back clearance.	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	ATCO does not issue a full push back clearance or rush into giving one.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.2.3 Move EFS on board (1 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved in the EFS	EFS does not accurately represent traffic situation			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation			V			V	V	
Wrong task executed	V	Incorrect strip moved	EFS does not accurately represent traffic situation			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Strip is put too early in the push back section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late in the push back section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.2.4 Scan of EINN OTW + RDP (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on EINN	Possible Runway incursion			V			V	V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V			V	V	
Task repeated	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V			V	V	
Task executed too early	V	Scanning of Shannon is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of Shannon is done at a later stage	Delayed situational awareness			V			V	V	
Task executed too much	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion			V			V	V	
Misread information	V	Scanning without paying attention	Possible Runway incursion			V			V	V	
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.2.5 Monitor the push back (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not monitor the push back	Possible ground incident			V		V		V	
Task execution incomplete	V	ATCO does not fully monitor the push back.	Possible ground incident			V		V		V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to monitor the push back	Possible ground incident			V		V		V	
Task repeated	V	ATCO monitors the push back several times.	Increased workload leading to a loss of time to perform other tasks.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO monitors the push back too early.	ATCO loses time to perform other tasks.			V			V	V	
Task executed too late	V	ATCO monitors the push back too late.	Possible ground incident			V		V		V	
Task executed too much	V	ATCO spends too much time monitoring the push back	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	ATCO does not monitor push back completely / thoroughly	Possible ground incident			V		V		V	
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.4.1 Check apron on OTW (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not check the Apron in EICK.	Lack of situational awareness potentially leading to an incorrect taxiing clearance.			V		V		V	
Task execution incomplete	V	ATCO only checks EICK Apron partially.	Lack of situational awareness potentially leading to an incorrect taxiing clearance.			V		V		V	
Task executed in wrong direction	V	ATCO checks Shannon Apron thinking is EICK Apron.	Lack of situational awareness potentially leading to an incorrect taxiing clearance.			V		V		V	
Wrong task executed	V	ATCO performs other tasks when he meant to check the apron	Lack of situational awareness potentially leading to an incorrect taxiing clearance.			V		V		V	
Task repeated	V	ATCO repeatedly checks the Apron in EICK .	ATCO loses time to perform other tasks.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO checks the Apron well in advance a taxiing clearance is issued.	Potential lack of new elements not being considered possibly leading to an incorrect taxiing clearance.			V		V		V	
Task executed too late	V	ATCO checks the Apron after a taxiing clearance is been issued.	Potentially incorrect taxiing clearance.			V		V		V	
Task executed too much	V	ATCO spends too much time checking the Apron in EICK.	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	ATCO only checks Cork Apron partially or not thoroughly.	Lack of situational awareness potentially leading to an incorrect taxiing clearance.			V		V		V	
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.4.2 Check EFS board for vehicles/aircraft (3 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on EFS board	Lack of situational awareness potentially leading to a ground incident		*V	V	*V	V		V	
Task execution incomplete	V	Incomplete scan of the EFS board	Lack of situational awareness potentially leading to a ground incident		*V	V	*V	V		V	
Task executed in wrong direction											
Wrong task executed	V	Scanning Shannon EFS thinking it is Cork	Lack of situational awareness potentially leading to a ground incident		*V	V	*V	V		V	
Task repeated	V	Repeated scan of EICK	ATCO loses time to perform other tasks.			V			V	V	
Task executed on wrong interface element	V	Scanning Shannon thinking it is Cork	Lack of situational awareness potentially leading to a ground incident		*V	V	*V	V		V	
Task executed too early	V	Scanning of Cork is done at an early stage	Increased workload as subsequent scans will be carried out		*V	V	*V		V	V	
Task executed too late	V	Scanning of the EFS is done at a later stage	Delayed situational awareness		*V	V	*V	V		V	
Task executed too much	V	Repeated scan of EICK	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	Incomplete scan of the EFS	Lack of situational awareness potentially leading to a ground incident		*V	V	*V	V		V	
Misread information	V	Scanning without paying attention	Lack of situational awareness potentially leading to a ground incident		*V	V	*V	V		V	
Other		Denotes that an Additional call received – phone/vehicle/SMC – increase workload -	Denotes Error criticality may increase								

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.4.3. Issuance of taxi instruction (5 s)									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not issue a taxiing clearance.	a/c is delayed.		V				V	V	
Task execution incomplete	V	ATCO does not issue a full taxiing clearance.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction	V	issues a taxiing to the landing aircraft.	Possible confirmation sought from the pilot on the ground.			V			V	V	
Wrong task executed	V	ATCO performs other tasks when he meant to issue taxiing clearance.	a/c taxiing is delayed			V			V	V	
Task repeated	V	ATCO issues a taxiing clearance two or several times.	Increase workload leading to a loss of time to perform other tasks.		V				V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues a taxiing clearance too early.	Possible confirmation sought from the pilot on the ground. ATCO loses time to perform other tasks.			V			V	V	
Task executed too late	V	ATCO issues a taxiing clearance too late.	Possible multiple requests sought from the pilot on the ground. ATCO loses time to perform other tasks.			V			V	V	
Task executed too much	V	ATCO spends too much time issuing a taxiing clearance.	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	ATCO does not issue a full taxiing clearance or rush into giving one.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.4.4 Move EFS on board (1 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved in the EFS	EFS does not accurately represent traffic situation			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation			V			V	V	
Wrong task executed	V	Incorrect strip moved	EFS does not accurately represent traffic situation			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Strip is put too early in the taxiing section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late in the taxiing section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.4.5 Scan of EINN on OTW and RDP (3 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on EINN	Possible Runway incursion			V			V	V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V			V	V	
Task repeated	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V			V	V	
Task executed too early	V	Scanning of Shannon is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of Shannon is done at a later stage	Delayed situational awareness			V			V	V	
Task executed too much	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion			V			V	V	
Misread information	V	Scanning without paying attention	Possible Runway incursion			V			V	V	
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.4.6 Monitor taxi and hand over to AMC (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAU TIO N
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not monitor taxiing a/c	Not spotting a Rwy incursion		*V	V	V* V			V	
Task execution incomplete	V	ATCO does not fully monitor the taxiing of the a/c	Not spotting a Rwy incursion		*V	V	V* V			V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to monitor the taxiing a/c	Not spotting a Rwy incursion		*V	V	V* V			V	
Task repeated	V	ATCO monitors the taxiing a/c several times.	ATCO loses time to perform other tasks.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO monitors the taxiing a/c too late.	Not spotting a Rwy incursion		*V	V	V* V			V	
Task executed too late	V	ATCO monitors the taxiing a/c too late.	Not spotting a Rwy incursion		*V	V	V* V			V	
Task executed too much	V	ATCO monitors the taxiing a/c too long.	ATCO loses time to perform other tasks.			V			V	V	
Task executed too little	V	ATCO monitors the taxiing a/c partially or not thoroughly	Not spotting a Rwy incursion		*V	V	V* V			V	
Misread information											
Other		Denotes that an Additional call received – phone/vehicle/SMC – increase workload -	Denotes Error criticality may increase								

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.6.1 Line up clearance (5 s)									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not issue line up clearance	a/c is delayed		V				V	V	
Task execution incomplete	V	ATCO issues an incomplete line up clearance	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to issue a line up clearance	a/c is delayed		V				V	V	
Task repeated	V	ATCO issues line up clearance repeatedly	Increased workload leading to a loss of time to perform other tasks.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues line up clearance too early	No impact			V			V	V	
Task executed too late	V	ATCO issues line up clearance too late	a/c is delayed		V				V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.6.2 Scan anemometer issue surface wind vector (3 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to pass wind vector information to landing aircraft.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Task execution incomplete	V	ATCO issues incomplete wind vector information.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Task executed in wrong direction	V	Wind vector information issued to aircraft landing EINN.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Wrong task executed	V	ATCO performs other tasks when he meant to issue surface wind vector	a/c departure is delayed			V			V	V	
Task repeated	V	ATCO reissues wind vector information.	ATCO loses time to perform other tasks.			V			V	V	
Task executed on wrong interface element											
Task executed too early											
Task executed too late	V	ATCO first issues wind vector information when aircraft close to landing.	Pilot unaware of wind vector information and potential associated hazards			V		V		V	
Task executed too much	V	ATCO continually issues wind vector information.	Frequency congestion. Time consuming.			V			V	V	
Task executed too little	V	ATCO fails to issue wind vector information.	Pilot unaware of wind vector information and potential associated hazards. Pilot requests updated information.			V			V	V	
Misread information	V	ATCO issues incorrect wind vector information.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.6.3 Request a departure from EICK APP (10 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not Request a departure from EICK APP	No release is possible. A/C is delayed.		*V	V		*V	V	V	
Task execution incomplete	V	ATCO does not complete a departure request from APP	Increased workload. No release is possible. A/C is delayed.		*V	V		*V	V	V	
Task executed in wrong direction		ATCO requests a departure from Shannon APP.	Increased workload		*V	V		*V	V	V	
Wrong task executed	V	ATCO performs other tasks when he meant to request a departure from EICK APP	a/c departure is delayed		*V	V		*V	V	V	
Task repeated	V	ATCO requests a departure from EICK APP several times	Increased workload			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO requests a departure from EICK APP too early	Perhaps a confirmation or an amended departure at a later stage, increasing the ATCO workload.			V			V	V	
Task executed too late		ATCO requests a departure from EICK APP too late	a/c departure is delayed		*V	V		*V	V	V	
Task executed too much											
Task executed too little											
Misread information											
Other		Denotes that an Additional call received – phone/vehicle/SMC – increase workload -	Denotes Error criticality may increase								

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.6.4 Scan of EICK runway (3 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan take off runway.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task execution incomplete	V	ATCO fails to scan take off runway thoroughly.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at wrong airport.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task repeated	V	ATCO continually scans runway	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task executed too early	V	ATCO scans runway again.	Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Misread information	V	ATCO fails to notice obstruction on runway.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Other		Denotes that an Additional call received – phone/vehicle/SMC – increase workload -	Denotes Error criticality may increase								

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.6.5 Scan of EINN OTW + RDP (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on EINN	Possible Runway incursion			V		V		V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion			V		V		V	
Task executed in wrong direction											
Wrong task executed	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V		V		V	
Task repeated	V	Repeated scan of EINN	Time consuming			V		V		V	
Task executed on wrong interface element	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V		V		V	
Task executed too early	V	Scanning of Shannon is done at an early stage	Increased workload as subsequent scans will be carried out			V		V		V	
Task executed too late	V	Scanning of Shannon is done at a later stage	Delayed situational awareness			V		V		V	
Task executed too much	V	Repeated scan of EINN	Time consuming			V		V		V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion			V		V		V	
Misread information	V	Scanning without paying attention	Possible Runway incursion			V		V		V	
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.8.1 Scan of EICK runway (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan take off runway.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task execution incomplete	V	ATCO fails to scan take off runway thoroughly.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at wrong airport.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task repeated	V	ATCO continually scans runway	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task executed too early	V	ATCO scans runway again.	Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Misread information	V	ATCO fails to notice obstruction on runway.	Runway incursion – miss obstacle on the runway.		*V	V	V* V			V	
Other		Denotes that an Additional call received – phone/vehicle/SMC – increase workload -	Denotes Error criticality may increase								

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.8.2 Issuance take off clearance EICK (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to issue take off clearance.	a/c delayed on the Rwy.			V			V	V	
Task execution incomplete	V	ATCO issues incomplete take off clearance.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to issue take off clearance .	a/c departure is delayed			V			V	V	
Task repeated	V	ATCO issues take off clearance several times.	Increased workload			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues take off clearance too early.	No impact			V			V	V	
Task executed too late	V	ATCO issues take off clearance too late.	Increased coordination with APP required -> increased workload.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.8.3 Interact with EFS (1 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved in the EFS	EFS does not accurately represent traffic situation			V	V			V	
Task execution incomplete											
Task executed in wrong direction	V	Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation			V			V	V	
Wrong task executed	V	Incorrect strip moved	EFS does not accurately represent traffic situation			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Strip is put too early in the Runway section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late in the Runway section.	EFS does not accurately represent traffic situation			V	V			V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.8.4 Scan of EINN OTW + RDP (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on EINN	Possible Runway incursion			V	V			V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion			V	V			V	
Task executed in wrong direction											
Wrong task executed	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V	V			V	
Task repeated	V	Repeated scan of EINN	Time consuming			V	V			V	
Task executed on wrong interface element	V	Scanning Cork thinking it is Shannon	Possible Runway incursion			V	V			V	
Task executed too early	V	Scanning of Shannon is done at an early stage	Increased workload as subsequent scans will be carried out			V	V			V	
Task executed too late	V	Scanning of Shannon is done at a later stage	Delayed situational awareness			V	V			V	
Task executed too much	V	Repeated scan of EINN	Time consuming			V	V			V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion			V	V			V	
Misread information	V	Scanning without paying attention	Possible Runway incursion			V	V			V	
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.10.1 Monitor take off roll/departure (60 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to observe take off roll of aircraft.	ATCO may miss incident arising on departure.		*V	V	*V	V		V	
Task execution incomplete	V	ATCO fails to monitor take off roll of aircraft thoroughly.	ATCO may miss incident arising on departure.		*V	V	*V	V		V	
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at incorrect airport.	ATCO may miss incident arising on departure.		*V	V	*V	V		v	
Task repeated	V	ATCO continually scans runway.	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element											
Task executed too early	V	ATCO scans runway before aircraft departs.	ATCO must scan runway again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to monitor departing roll as aircraft departing.	ATCO may miss incident arising on departure.		*V	V	V* V			V	
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not continually observe departing roll of aircraft.	ATCO may miss incident arising on departure.		*V	V	V* V			V	
Misread information	V	ATCO fails to observe incident arising as aircraft departs.	ATCO response to incident delayed.		*V	V	V* V			V	
Other		Denotes that an Additional call received – phone/vehicle/SMC – increase workload -	Denotes Error criticality may increase								

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.10.2 Scan of EINN OTW + RDP (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on EINN	Possible taxiway incident			V		V		V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible taxiway incident			V		V		V	
Task executed in wrong direction											
Wrong task executed	V	Scanning Cork thinking it is Shannon	Possible taxiway incident			V		V		V	
Task repeated	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning Cork thinking it is Shannon	Possible taxiway incident			V		V		V	
Task executed too early	V	Scanning of Shannon is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of Shannon is done at a later stage	Delayed situational awareness			V			V	V	
Task executed too much	V	Repeated scan of EINN	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan of the Runway	Possible taxiway incident			V		V		V	
Misread information	V	Scanning without paying attention	Possible taxiway incident			V		V		V	
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.12.1 Issue transfer clearance to next ATS unit (5 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to issue transfer clearance to next ATS unit.	Increased workload as it will need to be done at a later stage		V				V	V	
Task execution incomplete		ATCO fails to issue a complete transfer clearance to next ATS unit.	Confirmation sought by the pilot will lead to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to transfer the departure from EICK	a/c departure is delayed			V			V	V	
Task repeated	V	ATCO issues transfer clearance to next ATS unit repeated times	Increased workload			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues transfer clearance to next ATS unit too early	No impact			V			V	V	
Task executed too late	V	ATCO issues transfer clearance to next ATS unit too early	Increased coordination -> increased workload.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Simultaneously Landing on EINN and Departing on EICK			Task step: 1.12.2 Interact with EFS (1 s)								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved in the EFS	EFS does not accurately represent traffic situation			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation			V			V	V	
Wrong task executed	V	Incorrect strip moved	EFS does not accurately represent traffic situation			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Strip is put too early in the control zone section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late in the control zone section.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											