Human Performance Assessment of Multiple Remote Tower Operations Simultaneous Take-Off and Landing at Two Airports

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Abstract. Remote Airport Traffic Control Centre describes the goal of providing aerodrome control service at more than one airport from a geographically separated remote control centre. The technology is applicable to all airports, regardless of size or movement rate, in some cases potentially as a primary tower and in others as a fully functioning contingency or backup system. The innovative concept of multiple remote tower operations (MRTO) can maximize cost savings by using advanced technologies at the remote tower working positions, which permits less controllers to accomplish the same quantity and quality of air traffic management tasks at an airport. The aim of this research is to assess human performance on multiple remote tower operations by using the Human Error Template (HET). The results of this research demonstrate that advanced technology based on human-centered design has improved ATCO's performance in monitoring and controlling more aircraft from two different airports. OTW design permits the adjustment of the size of view of the selected airports (100%, 75%, 50% or 25%) based on ATCO's preference, but they are also able to zoom-in by PTZ to enhance visual searching. Furthermore, OTW allows different colors to distinguish different airports, 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. This is a very effective design to prevent runway incursions. The information presented by the RDP can facilitate ATCO predicting the flow of traffic and landing time at each airport, thereby facilitating enhanced decision making in respect of simultaneous movements at both airports. These new technology enhancements significantly increase ATCO task performance and in conjunction with a good human centered design the ATCO's decision making capability can also be enhanced.

Keywords: Air traffic control · Human-computer interactionling Human Error Template · Multiple remote tower operations Situation awareness

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1 Introduction

The development of advanced technology in the aviation industry has significantly changed the traditional air traffic management (ATM) system and air traffic controller (ATCO) task performance. The innovative concept of multiple remote tower operations (MRTO) can improve operational safety and maximize cost savings by using video panorama-based remote tower systems which permit less controllers to accomplish the same quantity and quality of air traffic management tasks at an airport. In Europe, the Single European Sky initiative has been set up to improve safety, minimize costs and environmental impact, and at the same time increase efficiency and capacity in order to meet the requirements of expanding air traffic [1]. A novel solution to fulfill these objectives is for a single air traffic controller to deliver control services to multiple airports from a remote location. The application of advanced technology suggests that air traffic controllers can visually supervise aircraft and airports from remote locations by video-link from a remote tower center (RTC). It is clear that visual features of detection, recognition, and identification by MRTO can fit the requirements by regulators and air navigation service providers (ANSP's) [2]. As the Remote Tower Concept was being researched for over 20 years, it became clear that it would differ fundamentally from traditional modes of local tower operation. Cameras and sensors could be placed anywhere on the field, and ATCO's would be presented a virtual picture of reality, enhanced by a number of advanced technical devices such as panoramic digital reconstruction with high resolution pan-tilt zoom (PTZ), and electronic flight strip (EFS). The advanced design of MRTO created some human-computer interaction (HCI) safety concerns, as this system expected one ATCO to perform four ATCOs' tasks with the assistance of new technology [4].

Air Traffic growth in recent years has highlighted deficiencies in infrastructure and airspace capacities resulting in increasing delays to aircraft and passengers. In order to address these concerns, the Single European Sky initiative has been set up with the following aims - improve safety, reduce airspace user costs and minimize environmental impact whilst at the same time increasing efficiency and capacity in order to meet the requirements of growing air traffic numbers [3]. ATCOs' visual search whether in a radar centre or an aerodrome control tower is critical for maintaining SA, but can be heavily influenced by the surrounding environment and equipment interface design. In order to gain a comprehensive understanding of the effects of different HCI design on cognitive function, it is necessary to apply a holistic approach which provides a comprehensive assessment of the impact on performance [5]. The HCI design of the Controller Working Position (CWP) including Electric Flight Strips (EFS), Radar Data Processing (RDP) and Out of Window screens (OTW) impacts an ATCO's cognitive processes in terms of attention distribution, situation awareness (SA) and decision-making. There can be three ATCOs in a traditional tower including the approach controller, air movement controller and surface movements controller. The multiple remote tower operation offers the goal of providing aerodrome control services for two or more airports from a RTC without direct presence at the airports under control. The aim of multiple remote tower operation is to deliver benefits in line with SESAR's high-level objectives, to enhance ATCO's situation awareness, to improve productivity, and to enhance system contingency and reduce workload [1]. It is based on the assumption that new technology will better facilitate ATCO's situation awareness and quality of decision-making, therefore, one controller would be able to perform all the tasks of monitoring, supervising, and communications involved in controlling aircraft and vehicles at two different airports which in a traditional system would be performed by four ATCOs. Air traffic controllers must make a rapid judgment of the situation that is being presented by their respective ATM system, and then take appropriate decisions to ensure aviation safety and maximize airspace and runway efficiency. Managing complicated ATM systems to maintain safe separation of 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 [6].

The Human Error Template (HET) has been developed specifically for the aerospace industry in response to Certification Specification (CS) 25.1302. In particular, it is intended as an aid for the early identification of design induced errors, and as a formal method to demonstrate the human factors issues in the design and certification process in aviation [8]. 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 HET error modes are credible for each task step, based upon the judgement of the 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 [9]. The HET error taxonomy consists of twelve error modes shown below:

1. Fail to execute
2. Task execution incomplete
3. Task executed in the wrong direction
4. Wrong task executed
5. Task repeated
6. Task executed on the wrong interface element
7. Task executed too early
8. Task executed too late
9. Task executed too much
10. Task executed too little
11. Misread Information
12. Other

For each credible error the participant provides a description of the form that the error would take, such as, 'Scanning Shannon airport thinking it is Cork airport'. Next, the participant has to determine the consequence associated with the error e.g. incomplete scan of the Runway at Cork, instantaneous to scan runway at Shannon. Finally, the participant then has to determine the likelihood of the error (low, medium or high) and the criticality of the error (low, medium or high). If the error is given a high rating for both likelihood and criticality, the aspect of the interface involved in the task step is then rated as a 'concern' requiring intervention. The main advantages of the HET method are that it is simple to learn and use, requiring very little training and it is also designed to be very quick to use. The HET method is also easily auditable as it comes in the form of an error proforma. The only real disadvantage associated with HET is that for large tasks, it may become laborious to perform [10].

2 Method

2.1 Participants

Five subject-matter experts participated in six focus group sessions. The subject matter experts ages ranged between 41 and 53 year old (M = 47.2, SD = 4.5); the working experience as qualified ATCO is between 13 and 25 years (M = 17, SD = 5.9).

2.2 Apparatus

The Remote Tower Centre is equipped with 2 Remote Tower Modules (Fig. 1) comprising of 15 screens in each (14 active & 1 spare). Each of the modules is equipped with the SAAB Electronic Flight Strip (EFS) and Radar Data Processing (RDP) display which is used only as a distance to touch down indication and not to provide a Radar Service. Each of the modules accommodates 2 controller positions, Surface Movements Control (SMC) and Air Movements Control (AMC). The SAAB Remote Tower camera system was installed at Shannon and Cork Remote Tower Sites. The Cameras are located at suitable positions to provide the exact same viewing aspect as the current physical Tower at each location. The out the window (OTW) visualization is made up of 15 full HD displays in a 220° configuration. 14 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 1920 × 1080 pixels, and have a refresh rate of 60 Hz.

2.3 Scenario

ATCO controls a Boeing-737 landing at Shannon airport whilst simultaneously controlling another Boeing-737 departing from Cork airport from the RTC situated 120 miles away in Dublin airport.

2.4 Research Design

All participants were supplied with a training package for the HTA and HET methodology which consisted of a description of the method, a copy of the methods associated error taxonomy, 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 method. Participants were also given a HTA describing the action stages involved when remotely controlling a B737 Aircraft landing at Shannon airport. The participants were also provided with access to the MRTO module located at Dublin airport to remotely control Shannon and Cork airports. Five subject-matter experts familiar with multiple remote tower operations and human performance participated in this research. Participants had also participated in 50 trials of MRTO to gain practical experience of using the system. The Hierarchical Task Analysis (HTA) method is used

Fig. 1. The Module of multiple remote tower control system comprised by Electronic Flight Strip (EFS), Out of the Window (OTW), Radar Data Processing (RDP), Information Data Processing (IDP) and Voice Communication System

to break down activities, scenarios, and tasks into single separate operations. This methodology enables a comprehensive step-by-step description of the task activities associated with the scenario described above [11]. The step by step breakdown of multiple remote tower operations included ATCO's operational behavior and their interaction with the various pieces of equipment in the MRTO such as EFS, OTW, RDP, and IDP during which time their task performance was noted. The operational action related to HCI on multiple remote tower operations included time to complete tasks and sub-tasks which were then were analyzed using the twelve error modes of HET.

Finally, participants had to determine the likelihood of the error (low, medium or high) and the criticality of the error (low, medium or high). If the error is given a high rating for both likelihood and criticality, the aspect of the HCI involved in the task step is then rated as a 'concern', meaning that it requires attention in order to assure and improve safety. The errors associated with a specific task were classed as 'Pass' or 'Concern' [8]. The definition of Pass was assigned to errors whose effects would not endanger the safety of MRTO operations (scores between 1 and 4). Conversely, the Concern rating applied to errors where there was a high probability of occurrence and their safety criticality was also high (scores between 6 and 9). 'Concern' highlighted HCI design issues which could lead to critical human factors accidents/incidents; which should prompt the designer/regulator to consider changes to, or redesign of, interfaces, procedures, and/or ATCO's training, in order to avoid these errors presenting in multiple remote tower operations (Fig. 2).

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

Fig. 2. The HET likelihood and criticality matrix with the Pass and Concern respectively highlighted in green and red (Color figure online)

3 Results and Discussions

The application of HET was based on the HTA to analyze step-by-step of multiple remote tower operations (Cork and Shannon airports). This permitted an accurate assessment of the actions and the cost of the effort and time required to complete the operational steps, such as checking the RDP to estimate the distance and timing of arriving flights, monitoring moving aircraft/vehicles on the aerodrome by OTW, or inputting information into EFS. The objective was to understand the limitations of human performance and human-computer interactions on multiple remote tower operations. Once the overall task goal of performing multiple remote tower operations has been specified, the next step is to break the overall goal down into meaningful sub-goals [11]. In the task, “simultaneous aircraft Landing at Shannon airport and Departing aircraft plus a Circuit at Cork airport”, the overall goal was broken down into sub-goals. All of these operational actions have to be assessed based on twelve error modes of HET to identify the design induced error related to HCI on MRTO by all participants. The example of HET evaluation form shown as Table 1.

The results of this research demonstrate that advanced technology based on human-centered design has improved ATCO’s performance in monitoring and controlling more aircraft from two different airports [12]. OTW design permits the adjustment of the size of the percentage of the selected airports (100%, 75%, 50% or 25%) based on ATCO’s preference, but they are also to zoom-in by PTZ to enhance visual searching. Furthermore, OTW allows different colors to distinguish different airports, 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 move toward the runway, he/she will not be able to permit another aircraft moving to 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 predicting the flow of traffic and landing time at each airport, thereby facilitating enhanced decision

Table 1. Example of HET output for predicting HCI design induced error on multiple remote tower operation

Scenario: simultaneously landing on EINN and departing on EICK			Task step: 1.2.4 scan of EINN OTW + HDP (5 s)								
Error mode	TIC K	Description	Outcome	Likelihood			Criticality			PASS	CONCERN
				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 (extra unexpected calls)		…if increasing workload, the likelihood of certain error modes may increase as well	Depending on the type, feed in turn into the criticality of the error…		V			V			

making in respect of simultaneous movements at both airports. These new technology enhancements significantly increase ATCO task performance and in conjunction with a good human centered design the ATCO's decision making capability can also be enhanced. Therefore, it is possible for one ATCO to perform the tasks originally designed for four ATCOs' to complete.

There are also some potential HCI risks to be aware of [6]. The aim of multiple remote tower operation is to deliver benefits in line with SESAR's high-level objectives. It is based on the assumption that new technology will facilitate ATCO's situation awareness and quality of decision-making, therefore, one controller would be able to perform all the tasks of monitoring, supervising, and communicating activities involved in controlling two different airports [1]. The results of this research based on 50 field trials and scientific research framework demonstrated that MRTO is a safe approach to control both air and ground movement for two low volume airports simultaneously whilst maintaining safety. However, how much is too much when it comes to tasks for a single ATCO? MRTO is safe whilst operations are normal, the evolution of a critical event at one or other of the airports has the potential to overload the single ATCO, this requires additional study and analysis before MRTO operations can be deployed.

Only two error modes raised safety concerns with HET for MRTO in this research, both task executed incomplete and misread of information on the operational step of 1.2.4 Scan of EINN OTW and RDP in five seconds. Though the majority of operational steps are marked as PASS with medium likelihood and low criticality (Table 2), such as task repeat on scan EINN runway was time consuming, task executed too late leading to lack of situation awareness, these do increase ATCO workload as the steps are required to be repeated to assure safety. 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 pilot request there is potential for workload to increase and time pressure to become more acute. The main advantages of the HET method are that it is simple to learn and use, requiring very little training and it is also designed to be a very quick method to use. The error taxonomy used is also comprehensive; it was based on existing error taxonomies from a large number of human error identification (HEI) methods [9].

Table 2. Summary of HET on simultaneously controlling aircraft landing and departing based on multiple remote tower operations

	Error Modes (below numbers shown as %) / Sub-task for performing Simultaneously Landing on EINN (green) and Departing on EICK (red) by one ATCO	Fail to execute	Task execution incomplete	Task executed in wrong direction	Wrong task executed	Task repeated	Task executed on wrong interface element	Task executed too early	Task executed too late	Task executed too much	Task executed too little	Misread information	Other
1	Answer phone to coordination call from EINN APP (10-15 seconds)	60	100	40	40	60	0	20	20	0	0	60	0
2	Insert strip into ARR sequence on EFS (3 seconds)	60	80	20	60	40	0	40	0	20	0	80	0
3	Check apron on OTW for push back approval on EICK(5 seconds)	60	100	40	0	40	20	0	40	20	0	100	20
4	Scan on OTW+RDP of EINN to monitor push back (5 seconds)	40	60	20	60	40	0	60	20	0	40	60	0
5	Acknowledge call + reply from EINN arrival (8 seconds)	60	80	60	20	80	40	0	40	0	20	80	0
6	Utilize OTW picture to identify A/C on approach (3 seconds)	80	100	0	40	20	0	60	40	20	20	80	0
7	Check EFS of EICK monitoring vehicles/aircraft for Taxi instruction (3 s)	60	80	20	60	40	60	40	20	0	20	100	20
8	Cross check OTW + RDP of EINN to maintain SA (3 seconds)	80	80	0	60	20	0	60	20	40	0	60	0
9	Scan runway for obstruction for landing clearance of EINN (15 s)	80	60	40	80	20	0	40	60	20	0	100	0
10	Record clearance to land on EFS (2 seconds)	80	60	80	60	40	20	60	60	0	20	80	0
11	Line up clearance for EICK (5 seconds)	60	80	40	60	20	0	40	20	20	40	80	0
12	Move EFS on board (1 seconds)	40	100	60	20	0	40	20	60	0	20	80	0
13	Scan anemometer issue surface wind vector on EINN (3 seconds)	80	80	80	20	60	40	0	80	40	20	100	20
14	Monitor aircraft touchdown and roll on EINN runway (10-15 seconds)	80	80	60	20	40	0	0	60	20	40	80	0
15	Scan of EICK runway for take-off instruction (5 seconds)	40	100	40	40	60	20	60	60	40	20	80	0
16	Issuance take off clearance EICK (5 seconds)	80	60	40	20	60	0	40	60	20	40	60	0
17	Issue runway exit and taxi route for EINN (8 seconds)	80	80	60	80	0	0	20	40	20	60	80	0
18	Cross check OTW + RDP on EICK for maintaining SA (2 seconds)	60	100	20	60	60	20	40	60	20	20	100	0

The patterns of fixations on the indicators or the areas of interest (AOIs) can reveal an operator's visual trajectory of attention on the processing tasks. Eye movement patterns shown that OTW is the most important source of information to ATCO to perform his task integrated with Pan-Tilt-Zone (PTZ). Moreover, the percentage of fixations on the relevant AOIs is deemed as the predictor of the overall SA performance. Again, the OTW is the highest percentage of fixation (76.67%). In addition, the fixation duration is the average time fixating on an AOI, which can reflect the level of importance or difficulty in extracting information. Fixation duration might reveal how long ATCOs sustain attention whilst scanning the information in order to completing the mission. Furthermore, EFS has the highest average fixation duration display. It reveals that EFS is either be the most important or the most difficult tool for managing the tasks associated with safely completing multiple remote tower operations (Fig. 3).

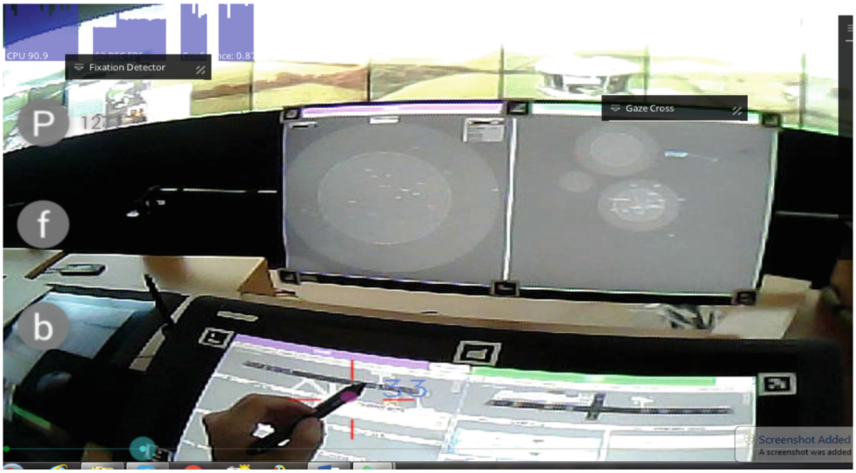

Fig. 3. ATCO's cognitive processing to plan the ground movement on EFS for multiple remote tower operation (EFS purple colour Shannon vs green colour Cork) (Color figure online)

4 Conclusion

Designing and managing human-computer interactions requires an understanding of the principles of cognitive systems and the allocation of functions between human operators and computer support systems. Human-centred design of multiple remote tower operations must be based on a strategic, collaborative and automated concept of operations to increase both airspace efficiency and safety [7]. The HET method is applied to determine whether or not the interface design under analysis is appropriate. The analysis assigned Pass or Concern was based on the associated error probability and criticality. The focus is on the human performance associated with the new technology in the MRTO and ensuring that the interfaces and support tools are used safely and efficiently to control aircraft both remotely and for multiple airports. The results demonstrate that advanced technology can provide sufficient technical support to one ATCO performing a task originally designed to be performed by four ATCOs, however, the application of this new technology also induced huge workload for one ATCO. It must be stated that this research is based on normal operations and does not consider the impact of an unusual situation or critical event during the operation. Should an unexpected event occur it is likely that work will snowball thus having a negative impact on ATCO's performance through increased time pressure and increased workload. This creates a need for further research on how to manage HCI issues to increase the safety margin within MRTO operations and provide more resilience for ATCO's cognitive abilities of decision-making. There is a need for further research on how to manage HCI issues for multiple remote tower operations to relieve ATCO's workload.

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