Factors Underlying Human Errors in Air Traffic Control

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CHAPTER 1: INTRODUCTION

Navigable airspaces are becoming increasingly crowded with an escalation in the number of accidents caused by human errors (Moon, Yoo & Choi, 2011). Air traffic control (ATC) is a highly complex job that requires controllers to utilise specific skill sets in response to a number of varying stimuli in order to ensure the safe passage of aircraft. Safety events or occurrences are defined by the International Civil Aviation Authority as “any event which is or could be significant in the context of aviation safety” (Skybrary, 2013). The term ‘occurrence’ refers to “operational interruption, defect, fault or other irregular circumstances that has or may have influenced flight safety and that has not resulted in an accident or serious incident” (Skybrary, 2013). Africa shows the highest regional accident rate despite accounting for the lowest percentage of global traffic volume; only 3% of scheduled commercial traffic (International Civil Aviation Organisation, 2013). Africa also shows steadily increasing traffic volumes, with an average annual increase of 6.2% within the region (International Civil Aviation Organisation, 2013). With the rise of traffic volumes and high accident rates in Africa, it is imperative to address the issues underlying the incidents in order to avert future incidents.

Safety occurrences or events emerge through a number of errors originating in two primary sources; technical and human. The International Civil Aviation Organisation (ICAO) categorise incidents into three primary categories; controlled flight into terrain, loss of control in-flight and runway safety related (Skybrary, 2013). Two of these three categories fall within ATC’s domain. Events can be initiated by both technical and human errors. In terms of human errors, there are two primary sources from which the error can originate; pilot and/ or air traffic controller (controller) actions. This research set out to explore and identify the underlying constructs at the base of one of the two primary originators of human error; controllers. The research thus focused exclusively on safety events that occurred through the fault of ATC. The research narrowed its exploration down to focus on six primary impacting variables; shift work, demographic factors, human processes, physiological variables, external factors and risk factors. Identifying the factors underlying human error in ATC will aid navigation by informing and focusing the development of prevention techniques.

1.1. Rationale

With the number of aeroplanes entering and exiting airport space, it is essential that operations and communication run smoothly. As seen from the description of the controller's job, this can be an extremely arduous task. There are a number of regulations (set forth by the International Civil Aviation Organization- ICAO) that must be adhered to so as to maintain safety standards. Incidents can range from a loss of separation to runway clearance. The International Civil Aviation Organisation (2009) has set forth a Safety Management System (SMS) in which they stipulate that organisations must have a formal process that identifies hazards in operations.

In accordance with these prescriptions, the Air Navigation Service Provider (ANSP) is alerted to any incidents that occur in the South African airspace. The ANSP then investigate the details regarding the incident, the actions taken leading up to the incident and its primary causes. Although these reports cover the incident and the primary source of that incident, they do not look in depth at the underlying factors that caused the human error as they serve more of a deposition function than an exploratory one.

The literature also shows paucity in the deep rooted factors underlying human errors. The majority of literature that addresses human errors in ATC either identify the primary cause for the incident (for example, communication breakdown) but not the root underlying that reason. This means that the impact that human factors, external factors, shift factors and demographic factors have on ATC capabilities has not been covered in great detail in previous research (Endsley & Rodgers (1998), Moon, Yoo, & Choi (2011), Arvidsson, Johansson, Ek, & Akselsson (2007), Isaac, Duchenne, & Amalberti (2002), Eurocontrol (1996).

Little research into this particular field has been done, with a primary focus on the development of human error identification systems and tools. Identifying the underlying causes of commonly occurring incidents will help future studies in designing interventions that may help eliminate these errors. Lastly, little if any research has been done in this field in South Africa. ANSP ensures that the details of the incident are properly investigated but there has been no research that looks at all the incidents together and identifies the underlying causes and trends. Identifying causes at the root of incidents in the South African region will guide future studies in tailoring solutions specific for the South African context.

1.2. Aims

The primary aim of this study was to explore and identify the underlying factors of human errors in ATC. A number of factors were explored, with the aims of the research to establish links between the six core variables (human factors, demographic factors, external factors, shift variables, risk factors and stated causal factors) and the safety events as well as to establish links between the core variables and the types of errors that occurred. In establishing links between the variables, the events and the types of errors, this research was able to identify the core factors underlying human error in safety events in air traffic control.

1.3. Research Questions

The research questions are posited as a means of identifying the underlying factors of human error in ATC. The questions are divided in relation to two primary facets of the research; safety events and human error. The research questions are consolidated into four primary questions:

1. Are there particular times in shifts when safety events are likely to occur?
2. What event variables and demographic variables are common between events?
3. Which human factors, external factors, risk factors and stated causal errors are related to safety events in air traffic control?
    - Which human factors are predictors of safety events?
    - What external factors are predictors of safety events?
    - What risk factors are predictors of safety events?
    - What stated causal factors are predictors of safety events?

The first three questions relate to the safety events and aim at establishing which shift variables, demographics and event variables are common between events as well as which human factors, risk factors, external factors and stated causal factors are related to safety events in ATC. The establishment of which variables are predictors of safety events will inform question four.

4. Are human factors, external factors, causal factors and safety events related to different types of human errors?
    - What errors are human factors related to?

- What errors are external factors related to?
- Are safety events related to certain types of human errors?
- Are stated causal errors related to certain types of human errors?

Question four aims at establishing links between the human and external factors that were found to predict safety events and human error types as well as establish a link between human error and the events themselves. The first sub-question aims at establishing what types of errors safety events are related to. This will inform the research as to which human errors are predictors of safety events. Next, the research investigates which of the predicting human and external factors are related to human errors that predict safety events.

1.4. Structure

This research utilized ANSP safety event reports in an attempt to identify key conceptual factors at the root of ATC. The report sets out a conceptual background in which the study is contextualized and the various concepts explored are explicated. The conceptual background is concluded with a reminder of the research questions and the technical terms used. The methodology section proceeds and covers the sample, instruments and procedure, ethical considerations and data analysis. The research results are then presented followed by a discussion of the results and a conclusion.

1.5. Acronyms used

For convenience, Table 1 lists the acronyms used.

Table 1. Acronyms used in the research

Acronym	**Meaning**
ATC	Air Traffic Control
ATM	Air Traffic Management
ANSP	Air Navigation Service Provider
FL	Flight Level
FPB	Flight Progress Board
FPS	Flight Progress Strips
HMI	Human Machine Interface
LoS	Loss of Separation
RAT	Runtime Analysis Tool
RI	Runway Incursion
RISC	Runway Incursion Severity Calculator
R/T	Radio Telephony
SACAA	South African Civil Aviation Authority
SSE	Safety Significant Event Scheme
SSI	Station Standing Instruction
STCA	Short-term Conflict Alert
TRACON	Terminal Radar Approach Control

CHAPTER 2: CONCEPTUAL BACKGROUND

This section provides a brief theoretical background relevant to the study. The literature review starts by providing a brief description of the responsibilities and roles of ATC as well as the general rules and guidelines under which they operate. It then moves on to cover the approach to human error this research adopted and the underlying core factors that will be addressed, namely; demographic variables, shift variables, external factors and human factors. The theory presented in the review aims to locate the study within the literature and aid in contextualising it. A systems approach was adopted as ATC was regarded as a system and factors within that system were evaluated and their impacts on one another explored. These factors may potentially not always reside within a controller's tasks, for example, but may lie within the processes in place and system designs.

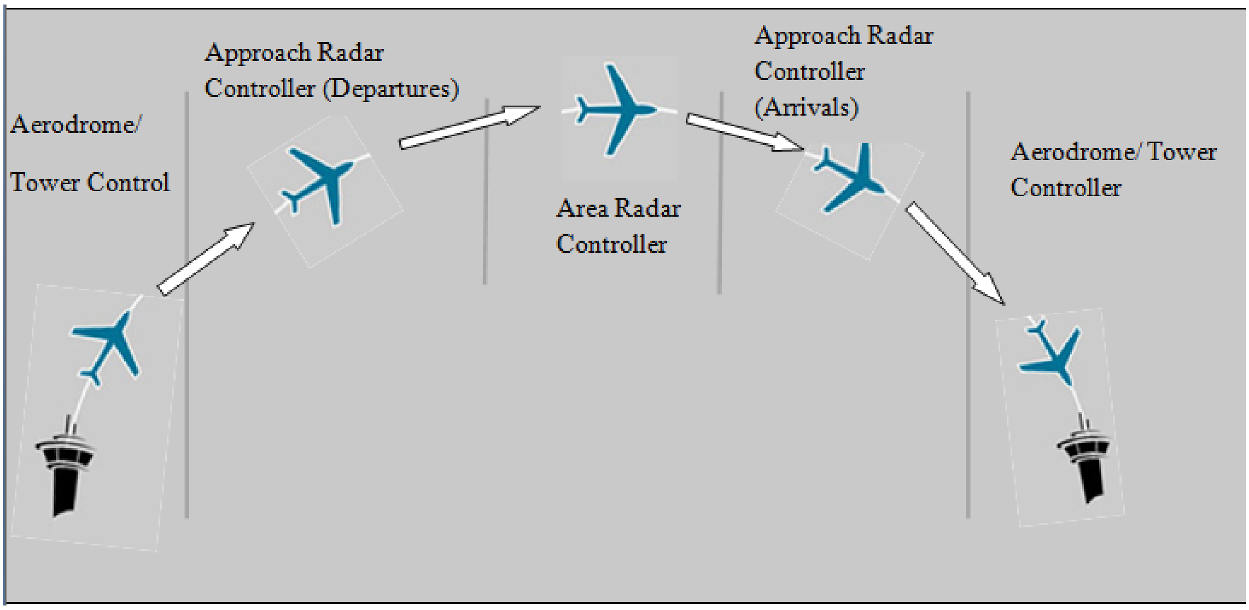
2.1. Air Traffic Control

The primary objective of ATC is ensuring the safe and orderly movement of aircraft through a nation's airspace (U.S. Office of Personnel Management, 1978). To accomplish this, ATC work is divided into three major functional groups, namely; "pre-flight briefing and assistance, and advisory services to pilots during flight, providing control and separation of en route air traffic; and control and separation of air traffic at airports" (U.S. Office of Personnel Management, 1978, p. 4).

These three primary functional services are divided among the three different air traffic facilities - flight service stations, air route traffic control centres and air traffic control terminals (U.S Office of Personnel Management, 1978). These three ATC facilities control different areas and heights and are in constant communication with each other as they hand aircraft over from one area to the next. This involves efficient coordination and communication between the control areas. The areas and corresponding facilities responsible for them can be seen in figure 1. ATC manages a number of primary phases, ground operations (which oversee from the gate to the taxiway to the runway), take-off and climb, cross country flights and approach and landing (Wickens, Mavor, & McGee, 1997).

Air route traffic control centres use radar surveillance to issue speed, altitude and directional instructions to pilots in order to keep aircraft properly separated. These are referred to as clearance issues throughout the research. A complete clearance issue includes complete speed, altitude and directional information. An incomplete clearance lacks one of these dimensions. In addition to their responsibilities for en route aircraft, they also provide approach control services to aircraft operating within their assigned area (U.S. Office of Personnel Management, 1978). ATC terminal staff depend on radar was well as a visual view of the runways (referred to in the research as radar and visual monitoring) in order to issue control instructions that provide separations. This assures the orderly movement of aircraft that are departing, landing and approaching for landing. This is done through the conveyance of essential traffic information to pilots regarding clearances and other crucial procedural instructions (U.S. Office of Personnel Management, 1978).

Figure 1. The different areas of control. Air Traffic Navigation Systems, 2011.



In order to maintain certain separations between aircraft, controllers have to be apt at interacting with pilots, controllers and a wide range of stimuli as well as making decisions based on this range of input. Following this, it is apparent that the controller must be able to execute multiple cognitive functions simultaneously (Moon et al., 2011). Depending on the station controllers assume during their shift, they will deal with a wide variation of stimuli and objectives.

Station standing instructions (SSIs) convey a multitude of regulations and procedures that must be adhered to at all times. Included in the SSI’s are the duty priorities of an ATCO and the correct phraseology to be used, among other aspects. The Duty Priority states that the ATCO is to "give first priority to separating aircraft and issuing safety warnings... good judgment shall be used in prioritizing all other provisions of service, based on the requirements of the situation at hand, within prescribed regulations and documentation" *(*SSI's ,Part 4 A General Operating procedure, section 4.7.1). This provides the scope and primary purpose of ATC.

There are a number of different control areas that controllers may assume during a shift. Controllers in different control facilities rely on different types of stimuli to perform their tasks. For example, controllers in the tower depend on a direct visual of the airport whilst controllers in TRACON (Terminal Radar approach control) and en-route environments depend on computer-based, partially automated radar displays (Wickens et al., 1997). This demonstrates the range of cognitive tasks required by controllers in order to complete different tasks successfully. The variety of visual stimuli presented by differing technological displays is coupled with the dynamic nature of the constantly changing images which change according to priorities. During standard operations, controllers must take various contextual complexities into account in order to manage traffic successfully (International Civil Aviation Organization, 2005). Complexities may include dealing with adverse meteorological conditions, congested airspace and malfunctions, all of which are considered in this research. This calls for a number of different types of cognitive functions such as attention and information processing in order to successfully perform the task. This also calls for a high level of situational awareness in order to maintain an awareness of the aircraft in the control area as well as project and predict the aircrafts' paths in reality based on a two-dimensional monitor. Air traffic control is a highly complex task that requires high levels of information processing by controllers in order to cope with the mental work load as well as the tasks' complexity.

Complexity may be increased when the common practice of combining sectors is implemented. It is stated that the combining of positions shall only be done under low traffic volumes (CAA Standards & Procedures Manual, 2013). The decision to combine sectors lies with ATC Planners on position and relies solely on good judgement as no accurate prediction tool exists with the capacity to predict traffic demands beyond 30 minutes (CAA Standards & Procedures Manual, 2013). The SSIs do not specify exact levels to guide ATCO's decisions regarding sector combinations. Controllers are cautioned against combining positions prematurely as this may result in overload of sectors.

Previous research has found that controllers report and prioritise key goals in the following order; avoiding violation of minimum separation standards, avoiding deviations from standard operating procedures, avoiding any disorder that may result in overload and lastly, making unnecessary requests to the pilot (Seamster, Redding, Cannon, Ryder, & Purcell, 1993). These goals are focused on preventing safety events and are discussed in more detail in the next section.

2.2. Safety Events

It can often be difficult to identify the scope or extent of a safety occurrence as it can be difficult to establish when an occurrence really began (Eurocontrol, 2003). There are two principal safety events that can occur through erroneous Air Traffic Controlling, namely; loss of separation (LoS) and runway incursions (RI**).** This section explicates these primary safety events, providing a brief description of the safety standards and what is considered an infringement of those standards.

Runway incursions. A runway incursion is defined as "any occurrence at an aerodrome involving the incorrect presences of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft" (International Civil Aviation Organization, 2007). The South African Civil Aviation Authority (SACAA) Standards and Procedure Manual states that aerodrome control is responsible for issuing information and instructions in order to prevent collisions between aircraft flying in, taking off, landing and aircraft in the vicinity of the aerodrome traffic zone. The aerodrome is also responsible for aircraft and vehicles, obstructions and other aircraft on the manoeuvring area (CAA Standards & Procedures Manual, 2013). Aerodrome controllers are required to maintain a constant visual watch over the area the aerodrome is responsible for in order to ensure that it remains free of obstructions, vehicles and other obstructions when needed for aircraft movements (CAA Standards & Procedures Manual, 2013).

If any vehicles are operating on a runway (including runway inspections or maintenance), the runway is to be kept sterile. This means that while these operations are in progress, no aircraft are to be allowed to line-up on the runway. This procedure does not apply to normal vehicular crossings but only to vehicles that will be on the runway for an extended time. For example, there are 3 daily runway inspections at O.R Tambo at dawn, dusk, and late night.

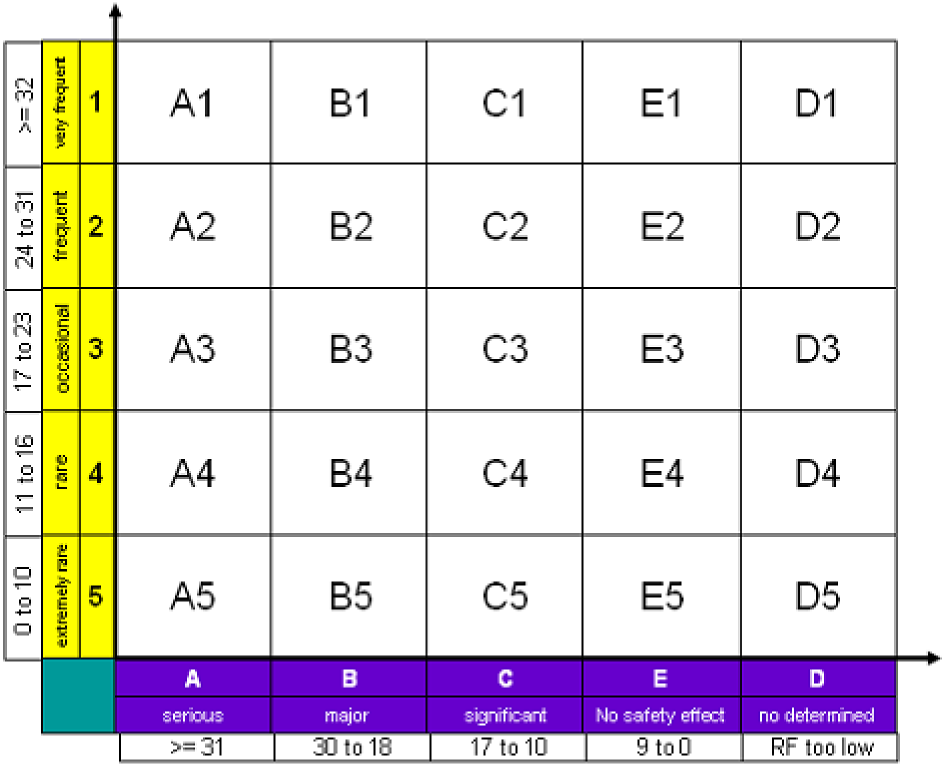
For the main inspections (dawn and dusk) the Inspection Team consists of a vehicle from Fire and Rescue Services, Aviation Safety and Airside Operations (CAA Standards & Procedures Manual, 2013). The runway must be kept sterile from any aircraft for the duration of these three daily inspections.

When permission has been given to cross or enter a runway, the controller must make use of a strip on the Flight Progress board (FPB) so as to serve as a memory cue. Flight Progress Strips (FPS) are displayed on the flight progress board so as to provide the maximum visual presentation of the traffic situation and possible traffic conflicts (CAA Standards & Procedures Manual, 2013). FPS are only to be removed from the progress board after transfer of the aircraft to another Air Traffic Service Unit or controlling sector. In addition to this, the Advanced Surface Movement Guidance and control system (A-SMGCS) displays information and is used to assist ATC in ensuring that runways are sterile before issuing landing or takeoff clearance.

Loss of Separation. A Loss of separations (LoS) involves an infringement of both horizontal and vertical separation minima in controlled airspace (International Civil Aviation Organization, 2013). The SACAA Standards and Procedure Manual contains the regulations regarding minima for horizontal separation and sets the minimum separation at 5 Nautical Miles (Nm).Vertical separation is infringed upon when the vertical distance between aircraft falls less than the prescribed minima. The SACAA Standards & Procedure Manual specifies the standards and regulations regarding vertical separation (CAA Standards & Procedures Manual, 2013). The vertical separation minima are 1,000 ft up to Flight Level (FL) 290 between all aircraft and 2,000 ft between all aircraft above FL410. A LoS is an event in which either horizontal or vertical separation minima are infringed upon.

Safety Standards and Ratings. There are a number of procedures that are considered compulsory for controllers. These procedures include the practice of read-back, issuing traffic information and using radio telephony (R/T) phraseology. Read-back is defined as a procedure whereby the receiving station repeats a received message or an appropriate part thereof back to the transmitting station so as to obtain confirmation of correct reception (ICAO Annex). Traffic information is issued in a strict format that must be followed and forwarded to aircraft in the airspace and R/T phraseology sets out the phrasing of communications to be used when controlling.

Safety events are scored according to severity and frequency. There are a number of different systems used to calculate the severity. In South Africa, the primary rating systems are the Runtime Analysis Tool (RAT), the Safety Significant Event scheme (SSE) and the Runway Incursion Severity Calculator (RISC).



>= 32	very frequent	1	A1	B1	C1	E1	D1
24 to 31	frequent	2	A2	B2	C2	E2	D2
17 to 23	occasional	3	A3	B3	C3	E3	D3
11 to 16	rare	4	A4	B4	C4	E4	D4
0 to 10	extremely rare	5	A5	B5	C5	E5	D5
			A	B	C	E	D
			serious	major	significant	No safety effect	no determined
			>= 31	30 to 18	17 to 10	9 to 0	RF too low

Figure 2. Safety event scoring system. Received from ANSP, 2013.

A safety event classified as an ‘A’ is considered a serious incident in which a collision is narrowly avoided, a ‘B’ class event an incident in which separation decreases and there is significant potential for collision, a ‘C’ classification as an incident characterized by ample time and/or distance to avoid a collision, a ‘D’ class event as an incident that meets the definition of runway incursion such as the incorrect presence of a vehicle, person or aircraft on the area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences and lastly an ‘E’ classification as an event with insufficient information, inconclusive or conflicting evidence (figure 2). The events are then rated 1 to 5, depending on the frequency with which the events occur (from extremely rare to very frequent). Following this, the most severe safety event is rated A1 and the least severe as E5.

2.3. Human Error

It has been estimated that between 60 and 90 percent of major incidents in complex systems such as aviation are caused by human error (Rouse & Rouse, 1983, as cited in Wickens & Hollands, 2000). Human errors are generically defined as "all those occasions in which a planned sequence of mental or physical activities fail to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency" (Salmon, et al., 2011, p. 9).

This research adopted an information processing approach to categorizing human error. In particular, it was guided by the scheme developed by Norman (1981, 1988) and Reason (1984, 1990 & 1997) (figure 3). The scheme follows the general format that a human operator is met by stimuli from the environment and has the potential to interpret the information correctly or incorrectly. Given that interpretation, the human operator may or may not have the intention to carry out the right action in response to the stimuli and finally may or may not execute the intended action correctly (Wickens & Hollands, 2000).

There are three distinct types of errors; slips, lapses and mistakes. Slips and lapses are "errors which result from some failure in the execution and or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective" (Salmon et al., 2011, p. 9). Mistakes are "failures in judgemental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision scheme run according to plan" (Salmon et al., 2011, p. 9). As seen from figure 3, mistakes are errors in interpretation or in choice of intentions. Slips occur when the right interpretation occurs in conjunction with the correct intention formulation but the wrong action is generated (Wickens & Hollands, 2000).

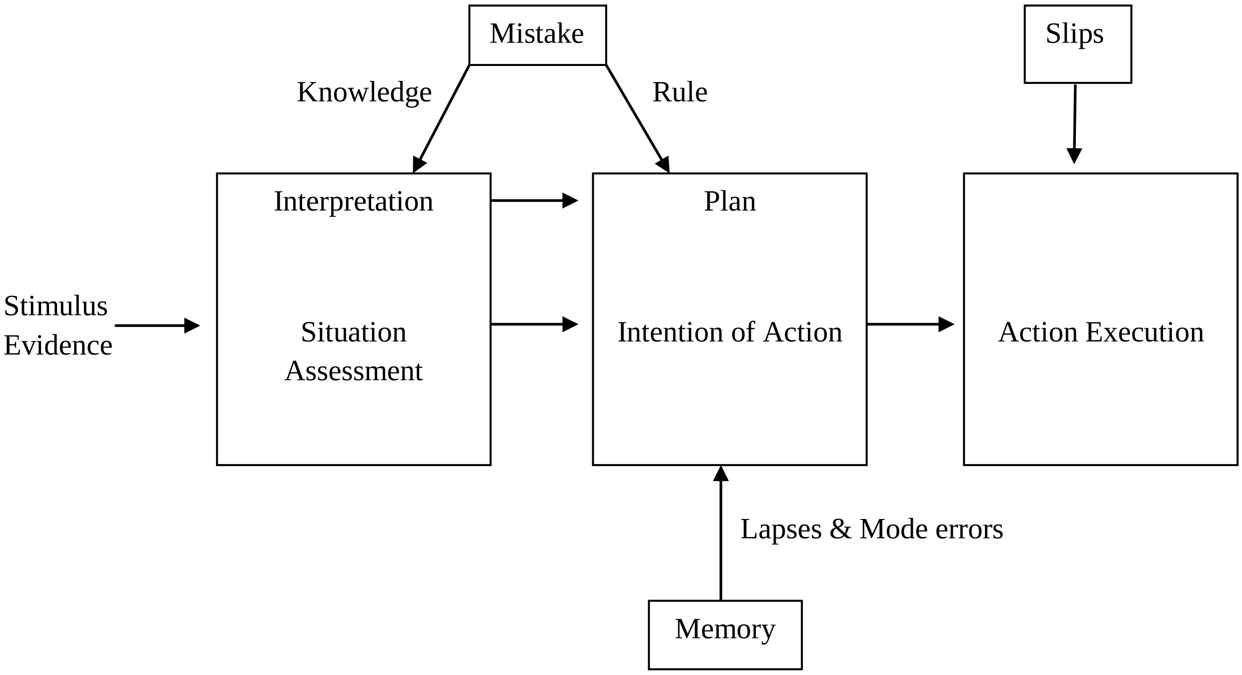


Figure 3. Information Processing Context for representing human error. Taken from Wickens & Hollands, 2000, p.494.

Following the working definitions, human operating errors can occur in two ways; through an action that goes according to plan when the plan was inadequate or when the action is deficient despite a satisfactory plan (Reason, 1990). In summary, Reason (1990) argues for three primary classification types of errors; skill-based slips, rule-based mistakes and knowledge-based mistakes. Execution failures correspond to skill based levels of performance and planning failures with rule and knowledge-based levels (Reason, 1990). Planning failures are classified as mistakes and execution failures as slips or lapses (Rasmussen, 1986). Figure 2 shows a summary of these errors adapted from Rasmussen.

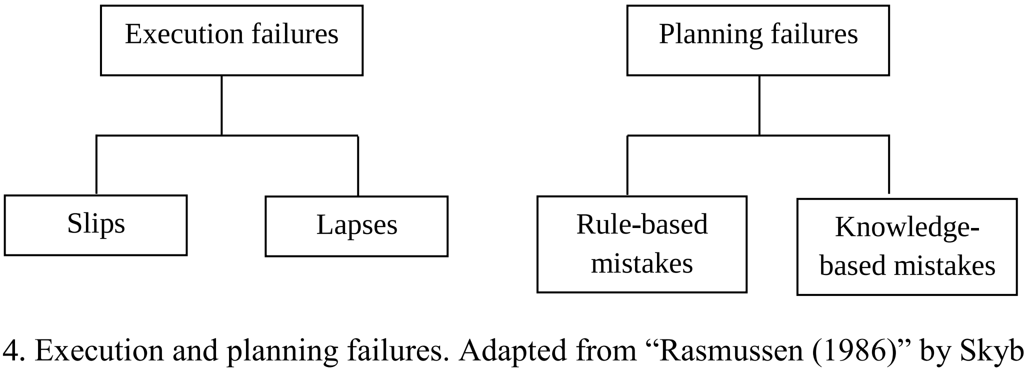


Figure 4. Execution and planning failures. Adapted from “Rasmussen (1986)” by Skybrary, 2013.

Errors are defined in ATC as “actions or inactions by the air traffic controller that lead to deviations from organizational or air traffic controller intentions or expectations” (International Civil Aviation Organization, 2005, p. 5). Examples of errors include not detecting a read-back error by a pilot and clearing an aircraft to use a runway that is occupied. This research took these errors and classified them into a type of error. For example, a controller that failed to detect an error in read-back has displayed an error in situation assessment which is indicative of a knowledge based error.

2.4. Factors Underlying Air Traffic Control

A large number of cognitive skills are required by controllers including; perception, attention, memory, information processing, decision making and attention (Eurocontrol, 1996). These cognitive skills need to be readily available to controllers and are often used concurrently. In addition, they are likely to interact with other factors relating to shifts and demographic variables in influencing the occurrence of safety events. Cognitive task analyses analysed knowledge structures, mental models, skills and strategies of en route Controllers and found that primary tasks reported by Controllers were primarily behavioural but included maintaining situation awareness (Seamster, Redding, Cannon, Ryder, & Purcell, 1993).

This section reviews the factors and theoretical constructs that contribute to controller performance. The theoretical constructs were identified mainly through a literature review. However, when analysing the safety report data, several additional factors (namely, shift variables, external factors and risk factors) were identified that and these were then included in the review below. Thus an iterative process was used to identify the relevant factors. Working definitions are given for each concept, links are made to ATC and a brief motivation is given for their inclusion in the study.

2.4.1. Shift variables (Covariate 1). Shift variables include time since start of shift (in minutes), time since position takeover (in minutes), time since last break (in minutes), hours since last sign off and days since last day off. As previously stated, there are a number of different control areas that controllers may assume during a shift. Time since start of shift indicates the time since the controller commenced that particular shift, whilst time since position takeover indicates the time since the controller has assumed a position. For example, a controller may work an hour on the aerodrome position, have an hour break and takeover a position on ground controls on which a safety event occurs thirty minutes later. In this case, the time since start would be noted as two and a half hours whereas time since position takeover would be noted as thirty minutes.

ANSP have stated that most events occur within the first 30 minutes of a shift, or the first 30 minutes after returning from a break or assuming a new position. Roster designs are not standardised at the moment and are dependent on the airport. ANSP is in the process of standardising rosters. Regardless of the unstandardised times, all rosters follow the guideline that controllers cannot work more than eight consecutive days without a day off, with shifts of 7 hours long. The duration of breaks differs from 30 minutes to 2 hours depending on the situation.

2.4.2. Demographic Factors (Covariate 2). Demographic factors refer to factors relating the structure of populations and often include age, gender and language knowledge (Stangor, 2011). Demographic variables differ with each individual and could potentially impact a controller’s performance. The demographic factors taken into account in this study were limited by the information provided in the reports and included age, gender and language proficiency. The International Civil Aviation Organisation (ICAO) grades English language proficiency on a scale from to 1 (lowest) to 6 (highest). In order to conform to ICAO Language Proficiency requirements, pilots, controllers and all others who use English in Radio Telephony (R/T) communication must be at ICAO English Language Level 4 (Operational) or above. Level five designates ‘extended’ and six, ‘expert’.

2.4.3. Human Factors (Covariate 3). The study of human factors is defined as “the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system” (International Ergonomics Association, 2014). Effective human performance is fundamental to ensuring operational safety in aviation. The human factors that are brought to ATC can lead to unintended errors of task management and professional judgement (Skybrary, 2013). The human factors considered in this research were workload, memory, mental models, attention, task engagement, situation awareness, information processing, decision-making and human-machine interface.

Workload. Rapid advancements in technology have resulted in complex work systems in which operators must adapt their performance to suit dynamic environments, concurrent task demands, time pressure and tactical constraints (Sheridan, 2002). Consideration must be taken for the workload placed on the operation of these complex systems (Loft, Sanderson, Neal, & Mooij, 2007). Workload refers to the capacity to process information in a task situation, with processing capacity dependent on the availability of processing modules, attentional resources and the state of the organism (Gaillard, 1993). Workload is a function of the task demands placed on an operator and the capacity of the operator to meet those demands (Hopkin, 1995 as cited in Loft, Sanderson, Neal, & Mooij, 2007). Workload covers a broad spectrum of human activity but this research limited its scope to include only 'mental workload' which limits the research to mental capacities (the capacity of the operator to meet task demands) and physical co-ordination (task demands) (Hancock & Meshkati, 1988).

Increases in air traffic density and complexity have substantially increased the demands on controller's mental workload (Wickens et al., 1997). It has been posited that high workloads can lower performance (Wickens et al., 1997) and that workload is influenced by traffic volume and complexity (Moon et al., 2011). This would suggest that increases in workload increase the probability of errors. Increase in traffic volume is a form of job stressor in the work environment. Endsley and Rodgers (1998) found that controllers were significantly less likely to make mistakes with lower levels of subjective workload than high levels. Environmental stressors impact on a controller's workload as traffic volume and complexity (external stressors) increase controller workload. Research shows that an individual's performance decreases when workload increases (Wickens, Gordon, & Liu, 1998). This study considered both the environmental stressors and the subjective view of the mental workload at the time of the event. The subjective view of mental workload was provided by controllers in the safety event reports immediately after the event, on a scale of 1 to 5. One denoted low, two; medium-low, three; medium, four; medium high and five; high mental workload. The subjective rating was taken for both traffic load and complexity separately, both impacting on controller workload. The environmental stressors considered in the research were the traffic load in the form of number of aircraft on frequency at the time of the event and aircraft movement in the hour leading up to the event. Environmental stressors also included investigator analysis of the traffic as being complex or not.

A number of airports in South Africa were included in the investigation reports, each with varying traffic volumes and staff necessary to deal with the different traffic volumes. For example, for the financial year 2011/2012, one of the international airports clocked 62000 international movements and 110 000 domestic movements. For the same period another international airport registered 1400 international flights and 55 000 domestic flights (Airports Company South Africa, 2013). The traffic volumes for the two airports differ significantly and these traffic volumes will ultimately affect the workload. It has been suggested by investigating officers that the qualities of ATC services deteriorate when traffic loading increases above quiet. Due to the nature of the medium with which controllers interact (i.e. via radio), it is difficult to predict exact traffic loading before hand and must be established through snapshot values of the amount of aircraft on radio frequency at a point in time. It is thus difficult to predict exactly when traffic volumes will increase above quiet.

Mental Models. Mental models are the “mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states and predictions about future system states” (Rouse & Morris, 1986, as cited by Zang, Kaber & Hsiang, 2009, p.2). This is a crucial aspect of ATC as it represents a controller’s knowledge of flight locations, conditions and intentions of aircraft in his or her designated area. Following from this, mental models adjusted to be more situation-specific are known as mental/traffic pictures (Eurocontrol, 1996). Mental or traffic pictures are the “actual mental picture of a situation represent[ing] a moment to moment snapshot of the actual situation based on the mental model and the actually perceived external cues. A series of mental pictures represents the actual mental model including the actual parameterization” (Eurocontrol, 1996, p. 10). The mental picture represents the mental picture of the traffic situation and the necessary actions a controller has taken and should take. Mental imagery plays a significant role in air traffic control and has been equated to concepts of situational awareness and mental models (Shorrock & Isaac, 2010).

Shared mental models occur when the members of a team organise their knowledge of team tasks, equipment, roles and goals in a similar fashion (Lim & Klein, 2006). Team mental models allow team members to coordinate their behaviours, especially when both time and circumstance prevent lengthy communication and strategising among team members (Lim & Klein, 2006). Under these restricted circumstances, team members must rely on pre-existing knowledge to predict the actions of teammates in order to respond in a coordinated manner to urgent, high staked task demands (Lim & Klein, 2006). ATC work primarily on their own but they must be able to co-ordinate with other controllers as well as pilots. A certain degree of shared mental models is required between controllers and pilots in order to be able to co-ordinate and anticipate actions.

Information Processing. A number of vulnerabilities inherent in human information processing have been found in ATC (Wickens, Mavor, & McGee, 1997). Information processing assumes that human beings receive information from the environment, act cognitively on that information in a number of ways and emit some response back to the environment (Wickens, Gordon, & Liu, 1998). This complements the model used to classify human error as there is a stimulus (the environment), some assessment of that stimulus and a reaction.

Information is received through various cell receptors for the senses, namely; sight, hearing, smell, taste and feeling. This implies that information can have any form; visual, sensual or auditory (Sinanovic & Johnson, 2007). The most crucial forms of information to ATC are visual and auditory information. Information processing (figure 5) is dependent on a number of faculties including perception, working memory, sensory memory and attentional resources (Wickens, Gordon, & Liu, 1998). Sensory memory holds detailed memory for a short period of time (for example visual sensory memory is held for approximately two to three seconds). Perception adds meaning to the information by comparing it with other information stored in long term memory (Wickens, Gordon, & Liu, 1998). Once the meaning has been assigned to the information, it is either reacted to or transferred to working memory. Working memory refers to both the short term memory for what is currently being processed and a form of conscious in which human beings compare and evaluate cognitive representations (Wickens, Gordon, & Liu, 1998). The greater task uncertainty, the greater the amount of information that must be processed during task execution in order to achieve a certain level of performance (Galbraith, 1984)

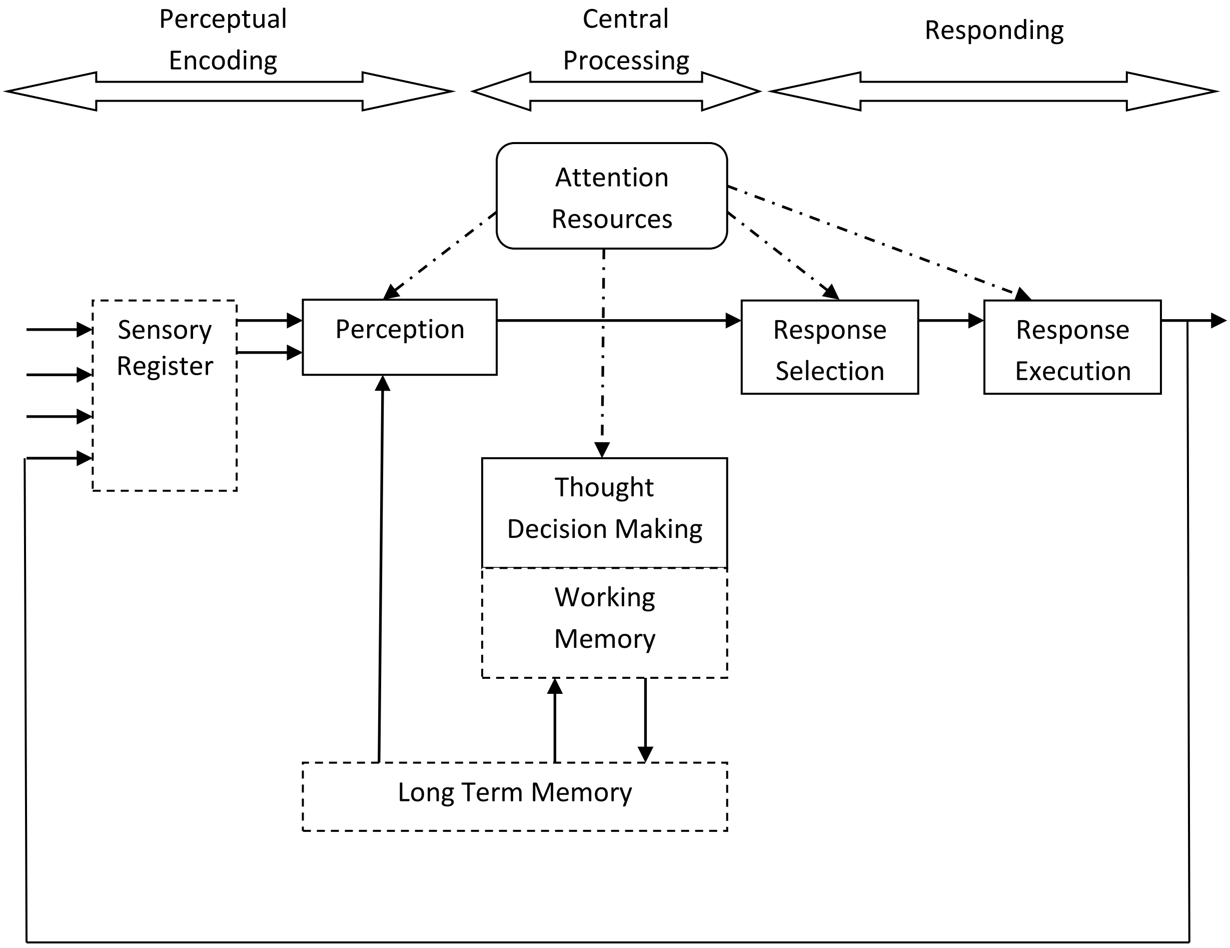


Figure 5. Generic model of human information processing with three memory systems. Taken from Wickens, Gordon, & Liu, 1998, p.147.

As can be seen from figure 5, information processing consists of perceptual coding, central processing and responding. Perceptual encoding is the "process by which the five senses translate environmental stimulation into mental representation" (von Hippel, Jonides, Hilton, & Narayam, 1993, p. 921). Perceptual encoding and by extension the 'perception' that is referred to in figure 5 include the registry of sensory information. Controllers are confronted with stimuli from various sources (such as radar displays, visual displays and radios) and must make use of all senses in order to register all crucial sensory information from the various sources. For example, a controller may need to encode perceptual information from a radar display or a communication from a pilot. Controllers also have to be able to pick up on and respond to Short Term Conflict Alerts (STCAs). A STCA is warning system that alerts controllers to both potential and actual infringements of separation standards. It can thus be seen that controllers are required to encode information through a number of senses.

Central processing incorporates actions that draw on attentional resources such as decision making and working memory. Responding requires both response selection and response execution. These constitute the information processing procedure of human beings. Research has found weaknesses in controller information processing with relation to detecting subtle or infrequent events, predicting events in three-dimensional space and in temporarily storing and communicating information (Wickens, Mavor, & McGee, 1997). Detecting infrequent events would show errors in sensory registration, problems of prediction would show errors in central processing whilst problems with storing information shows problems with working memory (central processing) and problems with communicating information shows errors in response execution. The errors in information processing that emerge through this research will be equated to errors in the relevant stages of information processing; perceptual encoding, central processing and responding. In this way, the research will be able to state in which stages errors in information processing occur.

It has been posited that schemata play a vital role in information processing in that they shape what we see and hear as well as how we store information and access that information at a later stage (von Hippel, Jonides, Hilton, & Narayam, 1993). A schema is a “plan,diagram or outline , especially a mental representation of some aspect of experience , based on prior experience and memory, structures in such a way as to facilitate (and sometimes distort) perception, cognition, the drawing of inferences, or the interpretation of new information in terms of existing knowledge” (Colman, 2006, p. 672). Schematic processing could possibly inhibit perceptual encoding in that schema guide interpretation and selective attention. This is supported by the model used in this study as attention resources guide perception (figure 5) which is in turn guided by schema. Schemata facilitate the interpretation of incoming information by allowing the perceiver to rely on prior conceptualizations in order to understand specific instances and current circumstances (von Hippel, Jonides, Hilton, & Narayam, 1993). In this way, perceivers with adequate schema do not need to pay much attention to either relevant or irrelevant information as they can rely on previously stored information and expectancies. An individual that lacks adequate schema must rely on an effortful integration of information (von Hippel, Jonides, Hilton, & Narayam, 1993).

By facilitating selective attention, schemata essentially enable perceivers to devote attentional resources to relevant information whilst ignoring irrelevant information (von Hippel, Jonides, Hilton, & Narayam, 1993). Following figure 5, the attention resources facilitate perception which leads into response selection. A breakdown in percetion would lead to erroneous responses.

Memory. Memory is a critical factor in establishing effective mental pictures and situation awareness in controllers (Shorrock, 2005). Memory is a cognitive function that is fundamental to most of a controller's tasks and is a common thread in most variables. Shorrock (2005) found that 38% of memory errors in ATC involved a failure to complete an intended action and states that controllers rely primarily on working memory and long-term memory. Working memory is a "temporary store for recently activated items of information that are currently occupying consciousness and can be manipulated and moved in and out of short-term memory" (Colman A. M., 2006). Working memory is used to encode, store and retrieve information regarding aircraft and the environment (Shorrock, 2005) but its capacity constrains cognitive abilities in numerous domains (Bradley & Tenenbaum, 2013). Information is constantly displayed for the controller to visually scan for changes, but the controller is required to keep information such as aircraft frequency, callsigns, route, flight level, aircraft type and location in his/her working memory (Shorrock, 2005).

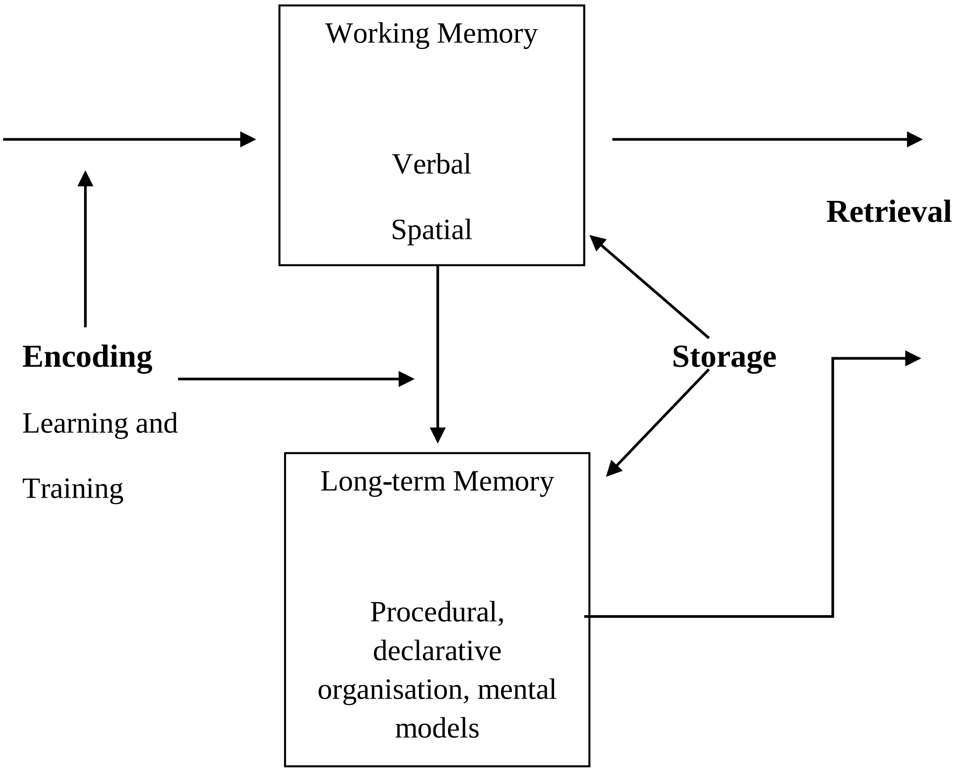


Figure 6. A representation of memory functions. Taken from Wickens & Hollands, 2000, p.242.

Long term memory is defined as, “a type of memory containing information that is stored for periods ranging from 30 seconds to many decades, often differentiated into episodic memory for events and experiences and semantic memory for information about the world” (Colman, 2006, p. 429). Long term memory has no known capacity, is fairly permanent, and supports information retrieval with little conscious effort whilst working memory retrieval requires conscious effort.

The model of memory functions (figure6) shows encoding in the first stage which involves the acquisition of information into the memory system and can take place by encoding information into working memory or transferring information from working memory to long-term memory. Learning or training requires the latter encoding (Wickens & Hollands, 2000). The second stage (referred to as storage) is the way in which information is held (or represented) in the two memory systems (Wickens & Hollands, 2000). Retrieval, the third stage, refers to one’s ability to access the information in the memory systems. If material cannot be retrieved, it is known as forgetting.

When accessing declarative memory, an individual is conscious of doing so (Goldstein, 2008). Declarative memory regards the accumulation of fact and data derived from learning experiences (Cohen & Poldrack, 1997). In other terms, it represents the outcomes of a number of processes which identify, appreciate and accrue the appropriate response to objects and persons encountered. Any complex event will entail information about visual objects, sounds, odours and so forth (Cohen & Poldrack, 1997). For example, controlling entails information from radar displays (visual) and information from radio telephony communications (auditory). Declarative memory is the system which chunks the information from the various information sources and binds them together to present the individual with a coherent representation of the event (Cohen & Poldrack, 1997). Declarative memory is a form of explicit memory for facts and events and is used to consciously remember facts, knowledge and events (Osipova et al., 2006). Procedural memory is a type of implicit memory which occurs when previous experience improves performance on a task even though one may not consciously remember the event (Goldstein, 2008). Procedural memory thus enables an individual to retain learned connections between stimuli and response (Tulving, 1987).

Decision-making. Aviation is a complex, safety-critical enterprise where decisions can affect the lives of hundreds of people as well as have vast economic consequences

(Eurocontrol, 2009). From an information processing perspective, decision making represents a mapping of copious information received to one or few responses (Wickens & Hollands, 2000). Decision making can be defined as a task in which (a) an individual must select one choice from a number of choices, (b) there is information available with respect to the decisions, (c) the time frame is longer than a second and (d) the choice is associated with uncertainty (Wickens, Gordon, & Liu, 1998). There are thus a number of factors that influence decision making, including the degree of uncertainty regarding the consequences of decisions, familiarity and expertise regarding the circumstances in which decisions need to be made as well as the time required for the decision process (Wickens & Hollands, 2000).

According to an information processing approach to decision making, there are critical components of decision making; selective attention, working memory and long term memory. Decision making involves cue reception and integration, hypothesis generation, hypothesis evaluation and selection, and the selection and generation of actions (Wickens & Hollands, 2000). This follows the general layout of both the human error and information processing approaches adopted by this research which involve to some degree the stimulus, an assessment of the stimulus and action formation. There are a number of cognitive limitations to factor into decision making. These include the amount or quality of the information cue, the amount of time allocated for each decision making activity, the attentional resources allocated to the activity, the amount or quality of the individual’s knowledge of the situation, an individual’s ability to retrieve relevant information or hypotheses and lastly an individual’s working memory capacities (Reason, 1990).

Aeronautical decision making is carried out in dynamic and complex environments characterized by ill-structured problems, copious amounts of information, uncertainty, competing goals, time constraints, high levels of risk and collaboration or task sharing among multiple individuals (Zsambok & Klein, 1997). Eurocontrol (2009) suggest a model of decision making that incorporates situation awareness and goals. In the model, the goal informs the planned action. The planned action incorporates the perception, understanding and forethought. This in turn informs the anticipated result which leads into an action (decision) and subsequent result. This result feeds back into the goal and forms the decision-making loop (Eurocontrol, 2009).

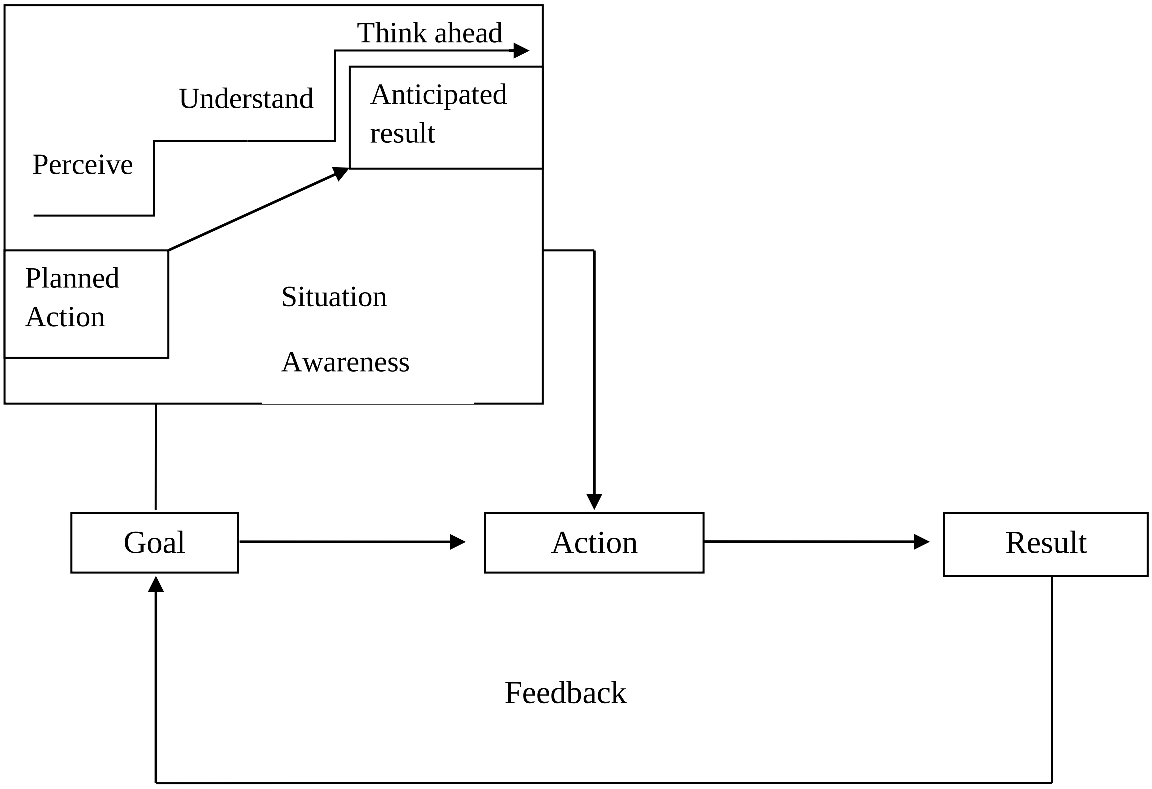


Figure 7. Decision making and situation awareness. Taken from Eurocontrol, 2009.

Attention. Attention is broadly defined as "sustained concentration on a specific stimulus, sensation, idea, thought or activity enabling one to use information processing systems with limited capacity to handle vast amounts of information available from the sense organs and memory stores" (Colman A. M., 2006). Attention can be subdivided into four primary groups; selective, focused, sustained and divided. Sustained attention refers to the ability to sustain attention over long periods of time (Demeter, Hernandez-Garcia, Sarter, & Lustig, 2011). At any given time there is a large amount of information sent to our brains through our senses. In order to be effective our actions must be directed to one object or location at a time (Chica, Bartolomeo, & Luianez, 2012). A selective mechanism is thus neccessary in order to select relevant information so that only these bits of information are processed deeply. It is posited that attended objects are processed to high levels leading to conscious awareness and voluntary reactions to them (Chica, Bartolomeo, & Luianez, 2012). Focused attention is the ability to attend only to relevant stimuli and ignore distracting ones (Nebel, et al., 2005). Divided attention occurs when we distribute our attention to two or more tasks. The ability to divide attention depends on a number of factors including practice and difficulty of the task (Goldstein, 2008). Although divided attention distributes mental resources, they are limited (Nebel, et al., 2005). Both focused and divided attention are aspects of selectivity. Controllers must be able to divide their attention without limiting their cognitive resources so that they are able to respond to all stimuli regarding ATC. It is crucial for controllers to be able to use aspects of selectivity in complex situations when there are conflicts and numerous sources of informaton. Sustained attention is also important as a controller needs to stay constantly vigilant during their shift so as not to miss any cues.

Sustained attention is similar to vigilance, and some researchers use the terms interchangeably. Vigilance has been defined as occuring when "attention must be focused on a source in order to detect a critical but infrequent event" (Gale & Christie, 1987, as cited by Donald, 2011) and refers to the "ability of organisms to maintain their focus of attention and to remain alert to stimuli over prolonged periods of time" (Warm, Parasuraman, & Matthews, 2008, p. 433). This form of attention that detects infrequent events is known as vigilance. Donald (2008) posits that definitions of vigilance overlook the complexities related to the significant events and defines vigilance as, "a capacity for sustained effective attention when monitoring a situation or display for critical signals, conditions or events to which the observer must respond" (Donald, 2008, p. 36). This definition is more apt for ATC as controllers encounter frequent significant events as opposed to infrequent. Their sustained attention is required to monitor all events both frequent and infrequent.

Coupled with these frequent events, controllers must also anticipate paths or events that may occur (i.e. are not currently occuring) and patterns that may materialise into a critical event. This shows how complex the nature of a controller's job is and the level of vigilance required is above and beyond merely detecting critical infrequent events. The definition posited by Donald (2008) incorporates cognitive processes such as the ability to identify, recognise and interpret the information presented. This definition incorporates the complex cogntive tasks required by controllers in order to remain fully vigilant. The vigilance decrement is a decrease in performance over time resulting in decreases in efficiencies through slower detection times (Lanzetta, Dember, Warm, & Berch, 1987). Sawin and Scerbo (1995) posit that a decrease in performance most commonly occurs after the first 20 to 35 minutes. ANSP have posited that most safety events occur within the first 20 to 35 minutes of a shift, if this is found to be true then this may be attributed to a decrease in detection performance or a vigilance decrement.

Studies have more recently come to focus less on influencing factors on vigilance decrements but on the role of attention resources in the vigilance decrement (Warm et al., 2008).

Traditionally, vigilience decrements were found to be caused by declines in arousal, more recently, evidence has shown that vigilance tasks impose substantial demands on the information processing resources of the observer (Warm et al., 2008). This approach to vigilance decrement postulate that the workload placed on operators performaing vigilance intensive tasks drain information processing resources, leading to lowered vigilance states. If safety events occur mostly within the first thirty minutes of the shift, this is likely not due to a vigilance decrement as the decrement decreases performance over time and by extension, safety events would occur further in to shifts than only within the first thirty minutes. These notions of performance and vigilance consider constructs such as task engagement and mental alertness.

Task engagement and mental alertness. Task disengagement has been studied under a number of varying rubrics including absent-mindedness, mind wandering, stimulus-independent thought and task unrelated thought (Cheyne, Solman, Carriere, & Smilek, 2009). Regardless of its label, general consensus is that task disengagement "consists of a state of reduced allocation of attention resources to environmental task-related stimuli" (Cheyne et al., 2009, p.93). Mind wandering occurs frequently and individuals are often caught thinking spontaneously about personal priorities, memories and other thoughts that are unrelated to the task at hand (Levinson, Smallwood, & Davidson, 2012). It has been found that when deprived of a task or involved in a task with insignificant demands on working memory, individuals devote their spare resources to personal musings (and task unrelated thought).

There are two primary differences in attention lapses. The first difference concerns task unrelated thoughts which translate to absent mindedness and disengagement. The second involves and pre-occupation with performance on a task that deploys attention in response to an environmental demand that exceeds one's capabilities (Smallwood, et al., 2004). This is relevant to controllers, whose attention is drawn to another stimulus or problem, disengaging them from their primary task. If a controller is inadequately trained or is new to the job, his/her attention resources are likely to be depleted more quickly. Alternatively, beliefs that the expectations of the task exceed his/her capabilities could result in thoughts about the risks of making incorrect decisions and concerns about performance, resulting in task disengagement.

Studies have found that a variety of external factors influence disengagement. Disengagement has been found to be high when the rate of stimulus presentation is slow, frequency of targets is low or task duration is long (Smallwood, et al., 2004). With regard to the safety event reports used in the current research, certain information was available which indicated conditions that could have been related to task disengagement. The reports did not directly measure disengagement but rather provided detail regarding the conditions surrounding the safety event which research has demonstrated to be related to disengagement. The presence of these conditions does not necessarily mean that disengagement occurred but rather taken to be indicative of possible disengagement. Indications of disengagement that were included in the analysis were decline in traffic load (slow rate of stimuli), inadequate break allocation (long task duration) and distraction (reduced allocation of attentional resources). The reports explicitly stated distractions such as subject-unrelated conversation. The decline in traffic load and break allocations are not direct indicators of disengagement but were taken to be indicative of possible disengagement. Task disengagement is also promoted through protracted, unvarying, familiar and repetitive tasks (Cheyne et al., 2009). It is possible that disengagement may be more applicable to certain airports that experience low traffic loads or alternatively at times in which there is little traffic loading.

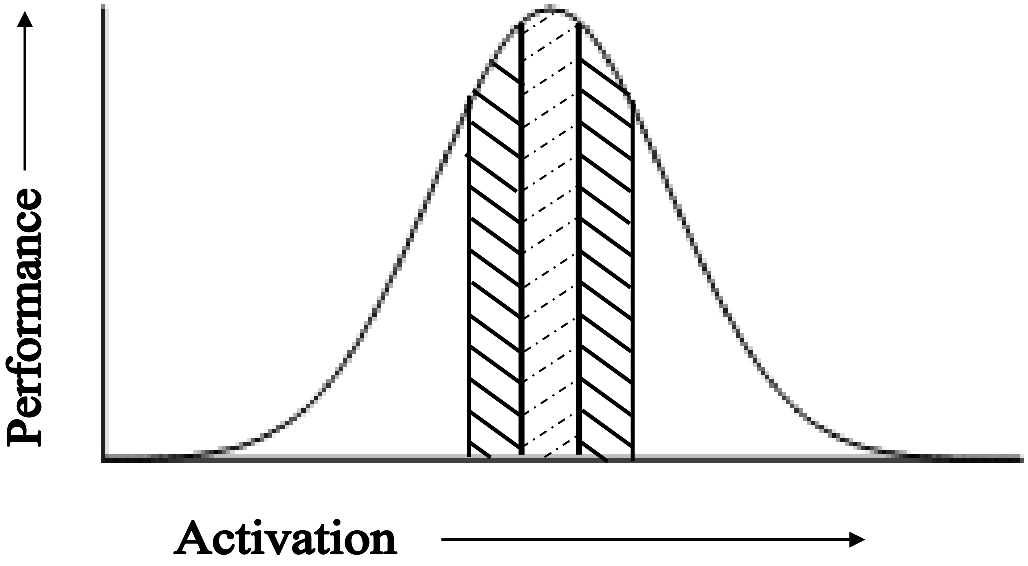


Figure 8. The inverted U-curve. Taken from Gilliard, 1993, p.994.

Cognitive processes transform sensory information into behaviour using logical operations. Energetical processes regulate the state of the organism and indirectly influence the processing of information (Gaillard, 1993). Every activity has an optimum activation level at which a task is best performed. The inverted U-curve (figure 8) shows the relationship between energetical levels (activation) and the efficiency with which tasks are performed. Performance efficiency on a task is low when the activation (energetical) level is either too high or too low (Gaillard, 1993). It can thus be seen that if activation levels are low (through slow frequency of targets, long task duration and boredom), optimal performance on tasks is not achieved.

Situation Awareness (SA). Situation awareness is an understanding of the state of the environment (including relevant parameters of the system). SA constitutes the primary basis for subsequent decision making and by extension, performance in the operation of complex, dynamic systems (Wickens & Hollands, 2000). SA is formally defined as a "person's perception of the elements of the environment within a volume of time and space" (Endsley, 1995, p. 65). Durso et al. (1999) apply SA to aviation and posit that it is the "continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events" (p.284). Expanding SA to an operator's understanding of a complex system extends SA research into dynamically changing environments where operators are responsible for achieving certain states (Durso, et al., 1999). Controllers must continuously be aware of the location of each aircraft in his/her sector, the aircraft parameters (such as speed and heading) and their projected future locations (Endsley & Rodgers, 1998). In highly complex situations, there is an increase in the cognitive nature of the task, highlighting the pertinent role of SA in order to understand the state of the environment (Durso, et al., 1999).

There are different levels of SA that must be applied to the situation that allows one to ascertain the degree to which an individual is situationally aware. At the lowest level (level 1) the operator needs to perceive relevant information (in the environment, system, self, et cetera.). Level 2 comprises that initial perception plus the integration of that data in conjunction with task goals. Lastly, the highest level (level 3) requires the prediction of future events and system states based on the understanding gained at level 2 and subsequently allows for effective decision making (Endsley, 1995). For example, a controller perceives two aircraft whose future paths display a loss of horizontal separation (level 1), realises that task goals are to maintain a safe separation distance (level 2) and predicting that maintaining original flight paths would deviate from this distance, changes flight paths so as to maintain separation. It is clear from this example that errors may occur at varying levels of SA. It is thus important to identify at which levels of SA the errors are predominantly occurring.

Endsley identifies certain internal and external factors that will affect SA. External factors include the workload, stress, interface design, task complexity and automation (Endsley, 1995). Internal factors include experience, communication, pre-attentive processing (the unconscious collection of information from the environment), attention, working memory, perception and mental models (Endsley, 1995). Applying this concept of SA to the context of ATC, SA would entail a mental picture of the location, flight, conditions and intentions of aircraft within an area in relation to each other (GATCSA, 2013). Situation awareness was stated as the primary cognitive task reported by controllers and included maintaining understanding current and projected positions of aircraft in the controller's sector in order to determine events that require or may require controller activity (Seamster, Redding, Cannon, Ryder, & Purcell, 1993). Controller understanding of aircraft projections (the future positioning of aircraft) is essential to ATC.

Some theorists have warned against considering SA as a causal agent in that when SA is considered as part of cognition, there is the danger of circular reasoning in which SA is presented as the cause of itself (Flach, 1995). Flach (1995) posits that SA is but another box in the information processing model. The differentiation and reduction of these concepts effectively confuse and complicate rather than clarify these concepts. This research will consider the circular nature of SA as a causal agent and its effects on the validity of conclusions if SA is found to be a significant predictor of safety events.

Human-machine interface. The construction of complex socio-technical systems has led to a greater demand for 'knowledge workers'. Knowledge workers are people whose primary function is to engage in rational work that requires discretionary decision- making. The primary reason these people are present in complex sociotechnical systems is to engage in adaptive problem solving (Vicente, 2002). There are various control areas that controllers may assume during a shift which rely on different types of stimuli to perform the various tasks. The variety of visual stimuli presented by the various technological displays is coupled with the dynamic nature of the constantly changing images displayed according to priority. This study adopted an ecological approach to human factors in that it was characterised by four principles; the reciprocity of person and environment, the representative design of experiments and evaluation, the primacy of perception and initiating while analysing the environment.

The ecological approach to human factors and human-machine interface (HMI) compliments the models used in this research. The various models (such as the decision making and SA models) stress the importance of perception and analysis of the environment. The ecological approach builds on this by recognising the crucial role that environment scanning and perception have on the reciprocal nature of the HMI. Furthermore, the ecological approach looks at specific problems of designing human-computer interfaces for complex sociotechnical systems (Vicente, 2002). Air Traffic Management (ATM) is a complex system that requires computer systems designed purely for the tasks of aircraft management. This study investigated the sociotechnical systems specific to ATM, noting any delays or errors in systems as well as errors in the use of the system, capturing the reciprocal nature of HMI.

2.4.4. External Factors (Covariate 4). This study considered a wide range of external factors, namely; recreational flights in the airspace, airspace design, complex traffic scenarios, workplace design, distracting phone calls, weather phenomena and combined sectors. These factors were extracted from report analyses as the primary external factors that were investigated in the ANSP reports.

Recreational flights in the airspace. Numerous reports involved recreational flights such as skydiving charters and paragliding in the airspace. When there are recreational flights in the airspace, a window is initiated in which the recreational flights operate. Controllers are responsible for instructing departing and arriving aircraft on which fly track to follow. A flight track is the path followed by the aircraft and there are a number of tracks that run next to each other on which aircraft can be placed. The window created by recreational flights changes flight tracks and the controllers need to be aware of these changes and apply them to aircraft entering and exiting the airspace. Changing the flight track may place aircraft on a track that ensures a buffer of the required 5nM from the boundary of the window in which the recreational flights operate.

Airspace design. Airspace organisation provides strategies, rules and procedures by which airspace is structured to accommodate different types of air activity and volumes of traffic (Department of Transport, 2010). Following this, some airspace are more complex than others, with varying sizes, flight paths and traffic volumes and these must be known by the controllers. The airspace design may include vast areas to be controlled by one controller or small airspaces that can be complex with many aircraft movements, leaving little room for error. Complex airspace designs were considered in this research to be an external factor that may have an impact on controller performance.

Complex traffic scenarios. Some reports included situations in which an unusual complex traffic scenario manifested. This could be due to variable flight information, aircraft low on fuel or other situations in which a common scenario manifests into a complex scenario in which the controller has to adapt plans to accommodate the complex scenario.

Workplace design. Organisational design traditionally refers to the division and co-ordination of tasks (Robbins, Judge, Odendaal, & Roodt, 2009). Workplace design was taken here not as a fixed structure but rather considered two facets of workplace design that emerged through the report analysis; workplace staffing as well as physical setting. The ‘workplace design’ variable in this study incorporated the physical design of the workplace. The physical workplace design included for example, the layout of the tower consoles in relation to the tower windows. In this example, the layout makes it difficult for controllers to execute a proper visual scan of both the runway and taxiway (figure 9). When the controller sits in the normal control position the consoles are too high to the left of the controller to comfortably scan the runway/taxiway to the left. This is considered poor workplace design. Any physical hindrance in the design of the workspace was considered to be a poor workplace design and was included in this variable.

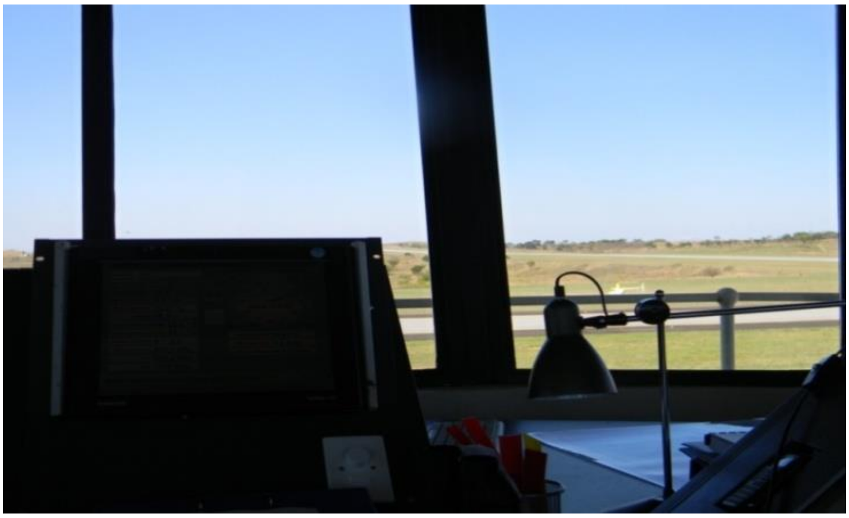


Figure 9. Photograph of a work station. Taken from an incident report.

Ergonomics refers to the science of work; the individuals involved, the way work is done, the tools and equipment used, the place worked in and the psychosocial aspects of work (Pheasant & Haslegrave, 2006). Anthropometrics is concerned with the matching of the physical demands of the working task (including monitoring runways and performing visual scans) to the workplace (among others) (Pheasant & Haslegrave, 2006).

The other aspect of workplace design encompassed notions regarding the staffing design of the workplace. The staffing design was largely concerned with whether there was adequate staffing at the time of the events as well as the supervision present at the time of the event. The reports included details regarding individuals having to work extended hours due to people being booked off sick or absent from work. Cases like this were considered to be indicative of poor staffing designs as there was not an adequate amount of staff available at the control centres. With respect to supervision, there are times when traffic loading is low in which case there may be a lack of management supervision. The lack of supervision may stem from beliefs that the situation will be able to be monitored without supervision (Eurocontrol, 2010). Regardless of the reasoning, this research considered a lack in supervision as a form of poor staffing designs.

Weather phenomena. Weather phenomena were included in the analysis as any weather phenomenon that incurred a change in operations. This may have included weather patterns that are cause pilots to fly under instrument meteorological conditions (meaning that pilots fly primarily by reference to instruments as opposed to visual references), change in runway use or weather avoidance.

Combined sectors. The combination of sectors follows strict rules regarding capacity levels as well as which sectors may be combined. For example, approach control may be combined with aerodrome Control, and flight information services may be combined with area control (South African Civil Aviation Authority, 2009). Snapshot values can be determined to provide the controllers with the means to determine demand prior to collapsing sectors. The Air Traffic Management (ATM) capacity document sets maximum capacity at 30 movements per hour. A movement is considered to be any one aircraft that either lands at or departs from an airport. Pace levels are used to describe the level of activity within the declared capacity of each sector. Pace levels form the basis for a comparison between different sectors and airports, and are expressed as a percentage of the declared capacity. The pace levels are described as follows;

- Pace level 1: 20% (Light)
- Pace level 2: 40% (Light – Moderate)
- Pace level 3: 60% (Moderate)
- Pace level 4: 80% (Moderate – Heavy)
- Pace level 5: 100% (Heavy)

Combining sectors should be done when expected traffic remains below 90% of merged sector capacity. Risks of combining sectors include underestimation of traffic and controller overload (Skybrary, 2013).

2.4.5. Risk Factors (Covariate 5). These factors were extracted from report analyses, taken from stated risk factors investigated in the ANSP reports. The most relevant and frequently stated risk factors that were included in the analysis were failure to respond to alerts, unclear position takeover, poor co-ordination standards, failure to pass on essential traffic information, poor radio telephony (R/T) phraseology and lack of memory cues in the environment.

Position handover/takeover. This is the process by which a controller on position is relieved of her duties and hands over to another controller. There are a number of procedures that need to occur before, during and post handover. Pre-briefing assimilates the new controller with the situation, what movements the current controller is dealing with and what needs to be done (Skybrary, 2011). The operational handover checklist for each section should be followed during the handover process and the outgoing controller must ensure that all relevant information has been passed on (Skybrary, 2011). The checklist include for example; weather, equipment, situation and traffic. Post hand-over, the handing over controller remains at the control position until such a time that it is clear that the taking over controller has full command of the situation (Skybrary, 2011). If any of these procedures are not carried out correctly or not all relevant information is passes, it may result in an unclear position takeover in which the taking over controller does not have all the information required to establish full command of the situation.

Co-ordination standards. Coordination standards and procedures aim at establishing safe and efficient mechanisms for the notification, exchange and transfer of flights between ATC units (Eurocontrol, 2012). Co-ordination lies largely on the communication of information regarding flight progress, flight plans and control information to necessary ATC units (Eurocontrol, 2012). Co-ordination is defined as the "organisation of the different elements of a complex body or activity so as to enable them to work together effectively" (Pearsall, 2005, p. 210). Co-ordination standards apply to controller-controller communications as well as controller-pilot communications. All parties must be aware of flight progress, flight plans and control information in order to work effectively. Adherence to these standards includes the use of correct R/T phraseology as well as passing essential traffic information. These concepts were discussed in the safety standards and rating section. Recall that traffic information must be passed to aircraft in a strict format using R/T phraseology.

Memory Cues. There is a large amount of information that reaches controllers whilst on position. Information must be managed so as to ensure that important information is not missed or forgotten (Eurocontrol, 2013). A lack of memory cues in the environment refers to controller error with respect to flight progress strips (FPS). If a controller forgets to or fails to move a FPS to indicate the movement of an aircraft, there is a lack of memory cue to serve as a reminder of the movements. For example, a controller may fail to move a FPS to indicate a runway occupancy, which would serve as a memory cue that the runway is occupied when a vehicle requests permission to enter the runway. The lack of memory cue may lead to the controller clearing the vehicle to enter the runway, causing a RI.

2.4.6. Stated causal errors (covariate 6). These factors were taken straight from the reports as the stated primary cause of the events. There were eight posited primary causal factors; memory lapse, mishear of read-back/hear-back, incomplete clearances issued, error in timing of clearances, misjudging aircraft, radar and visual monitoring failures, incorrect assumptions regarding separation and instructions issued to the incorrect aircraft.

Read-back/hear-back. Read-back is defined as the "procedure whereby the receiving station repeats a received message or an appropriate part thereof back to the transmitting station so as to obtain confirmation of correct reception" (Eurocontrol, 2013, p. 1). Following this definition, read-back is the practice by which the receiving station repeats the message and hear-back is the practice in which the transmitting station listens to the read-back to ensure that the message has been correctly received. An uncorrected erroneous read-back (known as a hear-back error) may lead to the aircraft's deviation from the intended clearance. This deviation may not be detected until the controller observes the divergence on his/her radar display (Eurocontrol, 2013).

Clearance Issues. Recall that ATC centres use radar surveillance to issue speed, altitude and directional instructions to pilots in order to keep aircraft properly separated. These are known as clearance issues. Occasionally, controllers issue clearances that are incomplete in that they may lack an aspect of the clearance such as altitude clearances. Controllers may also issue a clearance too soon or too late, effectively clearing an aircraft to an altitude too early or late resulting in inadequate separation between aircraft. Clearances may also be issued to the incorrect aircraft. When this occurs, the intended aircraft does not receive the clearances needed, whilst another aircraft receives the incorrect clearances.

Radar and visual monitoring failures. Controllers depend on radar was well as a visual view of the runways in order to issue control instructions that provide separations. This entails both radar and visual monitoring in order to ensure the orderly movement of aircraft that are departing, landing and approaching for landing.

Misjudging aircraft projections. Controllers need to assess both the current positions of aircraft as well as the projected position of aircraft. Aircraft projection is the future positioning of aircraft based on current positioning, direction and speed. It is essential for controllers to be able to assess aircraft speed and direction in order to assess whether future projections allow for the maintenance of separation standards. When aircraft projections are misjudged, the future projections as not correctly perceived, occasionally resulting in a reduction in separation standards between aircraft.

As can be seen, these primary factors can be linked theoretically to the constructs introduced under human factors. Memory lapses can be connected with memory constructs or to the memory components in the central processing stage of information processing. Mishear of read-back, misjudging aircraft, radar and visual monitoring failures can be related to errors in the various in the perceptual encoding stage of information processing. Issues with incomplete clearances, timing of clearances and instructions issued to the wrong aircraft can be rooted back to errors in the central processing stages of information processing. Before any analysis is done, it can be seen that all of the stated primary errors are related to issues in the stages of information processing.

The stated primary causes are considered here as it is important to capture the opinions of the investigating officers. The stated primary causes that are found significant in predicting safety events can then be evaluated in terms of the theoretical constructs that underpin them. This will assist in the overall evaluation of what human factors are at the root of the errors that lead to safety events in ATC.

2.5. Research Questions

1. Are there particular times in shifts when safety events are likely to occur?
2. What event variables and demographic variables are common between events?
3. Which human factors, external factors, risk factors and stated causal errors are related to safety events in air traffic control?
    - Which human factors are predictors of safety events?
    - What external factors are predictors of safety events?
    - What risk factors are predictors of safety events?
    - What stated causal factors are predictors of safety events?
4. Are human factors, external factors, causal factors and safety events related to different types of human errors?
    - What errors are human factors related to?
    - What errors are external factors related to?

- Are safety events related to certain types of human errors?
- Are stated causal errors related to certain types of human errors?

2.6. Jargon used

For convenience, Table 2 lists the jargon used in the conceptual background.

Table 2. List of jargon used

Jargon	Explanation
Aircraft projection	The future positioning of aircraft based on current positioning, direction and speed.
Clearance issues	The issue of speed, altitude and directional instructions to pilots in order to keep aircraft properly separated
Essential traffic information	Information regarding clearances as well as other crucial procedural instructions
Instrument meteorological conditions	Weather conditions under which pilots fly primarily by reference to instruments as opposed to visual references
Loss of separation	An infringement of both horizontal and vertical separation minima in controlled airspace
Mistakes	Failures in judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision scheme run according to plan
Radar and visual monitoring	The constant scanning of runways and radar in order to maintain separation between aircraft and ensure the orderly movement of aircraft.
Runway incursion	Any occurrence at an aerodrome involving the incorrect presences of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft
Safety event	Safety events or occurrences are defined as any event which is or could be significant in the context of aviation safety.
Slips and lapses	Slips and lapses are errors which result from some failure in the execution and or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective.

CHAPTER 3: METHODOLOGY

This research took the design of quantifying trends in qualitative data. The research design was cross-sectional, exploratory and non-experimental as there is no manipulation of the situation or variables, no control group and no random assignment of participants (Rosnow & Rosenthal, 1999).

3.1. Sample

A sample refers to a set of observations which form a part of an entire population (Howell, 2008). The research study was based on archival data in the form of incident reports that provided descriptions of safety events that occurred in civil aviation in the South African airspace. The sample includes all reports from the years 2010 through to 2012 with 32 reports from 2010, 27 from 2011 and 25 from 2012 making a total of 84 incident reports. The reports cover all airports in the South African airspace covered by the ANSP.

Factors underlying human errors will be analysed using these safety event reports provided by ANSP. These incident reports are drafted and collated by ANSP incident investigators. The sample for this study was thus South African controllers who have infringed certain airspace regulations resulting in a safety event. As the entire population of incident reports from the years 2010 to 2012 in South Africa was used, this constitutes a random, independent sample. In terms of the demographic variables, the mean age of the controllers involved in the events is 32.40 with $\times \sim N\ (32.40,\ 5.44^2)$ and a minimum age of 21 and maximum of 52. The most common occurring gender was male (Mo=1), with 72 males (77.4%) and 21 females (22.6%) making a sum total of 93 controllers. The most common occurring sector is reported as tower/approach (*Mo=11*).

3.2. Instruments and procedure

Permission to gain access to the reports was granted by ANSP. Full non-disclosure agreements were signed, allowing the researchers access to the reports. The reports were assessed by two researchers. One researcher covered years 2008 to 2010 as part of a separate study, and the years 2010 to 2012 were covered by this study.

The incident reports are based on the Human Error in Air Traffic Management (HERA) model (appendix 1). This system is the preferred technique among air traffic investigators and shows high inter-rater reliability (Lyons, Boive, & Van Damme, 2003). Incident investigators from ANSP have been trained in the HERA system. Incident investigations follow the detection and notification of a safety occurrence. Investigators perform factual information gathering in which they assemble evidence and information regarding the event. A preliminary report is compiled through various methods. For example, if a safety event occurred in a radar environment the radar recordings are impounded and reviewed. If it was a non-radar environment only the audio or frequency recording is impounded and investigated. In this step, causal factors are consolidated with the views of the individuals involved in the event and may prompt controller memory of details that were omitted straight after the event (Eurocontrol, 2003). An analysis phase follows in which arguments are put forward regarding why the safety event occurred and what technical, operational and underlying factors were involved.

In order to classify errors for incident analysis, the HERA technique aims to describe two types of factors, namely; the error and the context. In describing the error, the event is described in terms of what occurred (the error type), how it occurred (the error mechanisms) and why the mechanism failed (the information processing levels). In evaluating the context, the investigator notes when the event occurred, the individuals involved, the tasks being performed, the time sequence of the event and which information was involved (Eurocontrol, 2004). This analysis is then consolidated into a final report accompanied with recommendations for the issues that should be addressed, proposed remedial action as well as the controllers to receive remedial action (Eurocontrol, 2003).

3.3. Ethical Considerations

Since the study made use of archival data, no ethical approval regarding access to participants or samples was required. ANSP gave permission for the reports to be used for research purposes. The archival data (in the form of ANSP safety event reports) contains information that is both privileged and confidential and was required to remain so. The company concerned is responsible for protecting the rights of their employees as well as the individuals involved in the incidents. A non-disclosure agreement was signed by the parties involved (the University of the Witwatersrand and ANSP) stipulating the terms and conditions of the mental alertness project (appendix 2). Some of the safety event reports name the controller involved in the event, thus in order to ensure confidentiality and anonymity, no identifying information was reported in this research and the names were omitted from all analyses. As per the non-disclosure agreement, should this report be published, ANSP will be provided with a copy of the proposed thesis and given a period of thirty days to review the thesis.

Safety events reports have been kept in a confidential on-line file to which only the researchers and supervisors had access. As per the non-disclosure agreement, the copies of the safety event reports will be returned to ANSP once the research report is finalised and associated proceedings have concluded. A copy of the report and results will be made available to ANSP on conclusion of the research as well as for the WITS library. In the case that results are reported at conference(s) and in journal(s), the researchers will comply with the agreement stipulated in the non-disclosure agreement. The agreement specifies that ANSP requires 30 days to review the research report and to stipulate changes to be made should they find any part of the report to be commercially prejudicial. In addition, the non-disclosure agreement stipulates that ANSP might request that the research report and other publications be withheld from publication for a year after completion (Appendix 2).

3.4. Data Analysis

There were two primary parts to the analysis. Firstly, content analysis was performed on the safety event reports provided by ANSP. Although the reports were coded to some extent within the HERA framework, the reports were highly textual and require further analysis. The researchers developed a model that allowed for the coding of the information in the reports into various components. The framework was developed to capture both factors that emerged from literature as well as others that emerged from the reports themselves. This analysis allowed for a more in-depth approach to the reports in which the researcher was able to extract constructs pertinent to the study. A number of the reports involved more than one controller at fault. These reports were divided into the number of controllers involved in order to effectively capture the errors for each controller. When analysing event variables these reports were counted as one. This meant that these reports were viewed to represent one safety event but also captured the aspects of all the controllers involved. Once the reports were summarised into the model, they were then coded into quantifiable units of analysis.

The second part of the analysis involved statistical procedures, all performed in SPSS. Descriptive statistics were used in describing the sample and gaining insight into the shift and event variables. The second component of the statistical analysis was aimed at establishing relationships between human and external factors, and safety events and human errors respectively. This was performed in a number of steps. Initially a hierarchical cluster analysis was performed on the individual human factors umbrella variables as there were too many components for a cluster analysis. Hierarchical clustering is a method used to investigate grouping in data, over a variety of scales of distance, by creating a cluster tree called a dendrogram (MathWorks, 2013). The technique used agglomerative clustering which means that the procedure starts with each object representing an individual cluster; these clusters are subsequently merged according to their similarity (Mooi & Sarstedt, 2011).

The analysis clustered variables using Wards Method and by extension used a squared Euclidean distance, which is an agglomerative, complete linkage procedure (Mooi & Sarstedt, 2011). This method essentially draws a straight line between two variables to assess their proximity and ultimately their similarity, which is then compared with other variables and grouped according to similarity (Mooi & Sarstedt, 2011). The Agglomeration schedule, dendrograms and distance matrices were reported.

The dendrogram represents a multi-level hierarchy, where clusters at one level are joined as clusters at the next higher level and thus allows for the discerning of what level of clustering is most appropriate in the specific application (MathWorks, 2013). The dendrogram was used to determine the number of clusters for each umbrella variable. This was determined by looking at the point at which breaks occur at greatly increased distance levels (Mooi & Sarstedt, 2011). The squared Euclidean distance is reported in the 'coefficients' column of the Agglomeration Schedule and the difference *(d)* between distances establishes the number of clusters. Small coefficients indicate that relatively homogenous clusters have been merged whilst large coefficients show that groups containing dissimilar members have been merged. A coefficient cut off in SPSS lies around 9.0 (Gebotys, 2000).

The Agglomeration schedule reports the variables that are clustered as well as the stages at which they were clustered. The dendrogram (tree) provides a visual representation of this schedule. Using the schedule, the dendrogram and agglomerative schedule, the researcher discerned the number of clusters under each umbrella variable. Umbrella variables containing less than 3 sub variables did not have the minimum number of variables required for a hierarchical cluster analysis. The sub variables were thus chosen as the clusters under those umbrella variables. This was the case for decision making, mental models and mental alertness. Once the number of clusters per umbrella variable was established, variables were recoded into those clusters. This approach was adopted as there were too many variables under each umbrella variable to enter into a cluster analysis. The second part of the analysis involved the clustering of the clustered human processes variables, unclustered physical variables and unclustered external factors variables around the events as well as errors. These clustered were then evaluated and it was noted which variables clustered around the events and errors respectively.

The variables that were clustered around events as well as errors were then put through a logistic regression in order to establish the overall association between them and establish how well these clusters predict events and variables. Logistic regression provides knowledge of the relationships and strengths among variables (Sage, 2013). Logistic regression was chosen instead of a discriminant function analysis as the data included dichotomous response variables and categorical explanatory variables. Logistic regression is a method for testing relationships between one or more quantitative and/or categorical explanatory variable and one categorical outcome (Seltman, 2013). Logistic regression ultimately models the success probability as a function of the explanatory variables.

Logistic regression faces a number of assumptions that are less stringent than the assumptions of normality in discriminant function analysis. Logistic regression assumes random independent sampling, linearity between the Independent variables and logit of probability and model satisfaction. This means that there are no assumptions of normality, linearity or homogeneity of variance for the independent variables. The minimum number of cases per independent variable is 10, using a guideline provided by Hosmer and Lemeshow (Hosmer, Lemeshow, & Sturdivant, 2013). This requirement is met with the number of cases for each variable sitting at 94 ($n=94$). To test linearity, random IVs were chosen and entered into binning methods. Binning is a process in which individual data values are grouped into one instance of a graphic element (IBM, 2011). No differences were found between results including bins and those including original clusters. This may be because clustering is to some extent a similar process to binning, in which individual data values are grouped with others. Each regression looked at model fit, ensuring that the last assumption is met for every regression.

A limitation that this study faces is the consequences of a small to moderate sample size on logistic regressions. The phenomenon of small studies reporting large effects is due to systematically induced bias away from the null (Nemes, Jonasson, Genell, & Steineck, 2009). This study employed logistic regression on a small to moderate sample size, meaning that some cases may overestimate the effect measure. It is noted in such case that discretion must be used when interpreting results.

CHAPTER 4: RESULTS

4.1. Introduction

The results section presents the outcomes of the study through the reporting of the statistical analyses performed. This section starts with reports of the results in relation to safety events, effectively answering research questions 1 to 3 followed by results in relation to human error, answering research question 4. As this research is extremely technical in nature, the reader is reminded of the summary table (Table 2) of all jargon used on page 38. The results are reported in a constant format for each section, evaluating the cluster analysis in which the agglomeration schedule and dendrogram are provided followed by the results of the logistic regressions. It is noted that when factors are referred to as a 'significant predictor', this denoted that it showed to be statistically significant in the chi-square facet of the logistic regression at the 5% level of significance ($p < .05$). Factors are only considered to be significant predictors if statistically significant and not merely because they occurred most frequently.

Where large odds ratios occur, these are noted as a limitation of logistic regressions and may reflect an overestimation of the chances of the event occurring. Large odds ratios reflecting overestimations are possible outcomes in logistic regressions used in studies with small to moderate sample sizes. It is posited that these overestimations occurred when there were few observations for one of the explanatory variables (Nemes, Jonasson, Genell & Steineck, 2009).

4.2. Shift Variables, event variables and demographic variables

The first research question asked whether there are particular times in shifts when safety events are likely to occur. The most common occurring time of a safety event since the start of shift was 30 min (*Mo=30*). The most frequent occurring reported minutes since last break is 20 (*Mo=20*) and the most common occurring time since position takeover is 32 *(Mo=32*). The most common occurring duration of breaks was 60 min, with 12 being the most frequent number of hours reported since last sign off (Table 3). Because of the high range of times reported for *time since start* and *minutes since last break* (*R=441 & R=225*) and the extreme high values, means cannot be looked at for these variables as the extreme numbers pull the mean in one direction, ultimately positively skewing them. The modal values and means do not allow for any decisive conclusions to be drawn. In order to get a better understanding of times in a shift in which events occur, the data must be grouped into time periods.

Table 3. Descriptive statistics of shift variables.

	Time since start (min)	**Time since position takeover**	**Minutes since last break**	**Duration of last break (min)**	**Hours since last sign off**	**Days since last off day**
Mean	153.26	44.89	50.80	59.49	38.12	5.34
Median	123.50	32.00	41.50	60.00	24.00	2.00
Mode	30	32	20	60	13	2.00
Std. Deviation	116.92	41.49	42.75	40.28	39.94	11.97
Range	440	186	225	240	215	60
Minimum	1	1	0	0	1	0
Maximum	441	187	225	240	216	60

Table 4. Frequencies for grouped time since start of shift.

Minutes	Frequency	Percent	Valid Percent
0 -30	17	18.1	18.5
31 – 60	9	9.6	9.8
61 – 90	4	4.3	4.3
91 - 120	11	11.7	12.0
121 – 150	11	11.7	12.0
151 – 180	6	6.4	6.5
181 – 210	7	7.4	7.6
211 – 240	5	5.3	5.4
241 – 270	5	5.3	5.4
271 - 300	4	4.3	4.3
301 - 330	3	3.2	3.3
331 - 360	4	4.3	4.3
361 - 390	4	4.3	4.3
> 391	2	2.1	2.2
Total	**92**	**97.9**	**100.00**

When grouped into time periods of 30 minutes, the most frequent occurring times are within the first 30 minutes (f=17) followed by minutes 91 to 120 (f=11) and minutes 121 to 150 (f=11) (Table 4). Of the 92 reported times since start of the shift, 18.48% of the controllers were involved in an event within the first 30 minutes of a shift, 11.96% within minutes 91 to 120 and 11.96% within minutes 121 to 150. If grouped into hours, the first hour is the highest with 28.26% of the safety events occurring within the first hour, followed by 23.91% of events occurring between the 90th and 150th minutes. When grouping time since position take over into time frames of 30 minutes, the first 30 minutes of a position takeover is the most frequent occurring time (*f=23*), followed by minutes 31 to 60 (*f=10*).

A logistic (logit) regression was run on the shift variables and LoS and RI respectively, showing that there was sufficient evidence to suggest that one of the IVs (time since start, grouped shift times and grouped time since position takeover) is a predictor of LoS ($\chi^2_{(3)}$=21.47, p=.0 < .05) and RI ($\chi^2_{(3)}$=21.47, p=.00 < .05). Only time since start was found to be a significant predictor for both LoS ($\chi^2_{(2)}$ =5.11, p=.02 < .05) and RI ($\chi^2_{(2)}$ =5.11, p=.02 < .05). The direction of the prediction for LoS was positive ($\beta_1 = .02 > 0$) but negative for RI ($\beta_1 = -.02 < 0$). It is interesting to note the change in direction between the prediction of LoS and RI. The direction suggests that the longer the time since start of a shift, the more likely a controller is to be involved in a LoS but less likely to be involved in a RI. The odds ratio showed that at 1minute into the shift, a controller has a 0.14 % probability of incurring a LoS. At 30 minutes, a controller has a .25% chance of incurring a LoS, although the probability of a safety event remains low in both cases. The odds thus increase by 1.7% of that proportion with every minute on shift. At 30 minutes, a controller has a .46 % chance of incurring a LoS and a .84% chance at 90 minutes. At 120 minutes, a controller has a 1.54% chance of incurring a LoS and a 2.80 % chance at 150 minutes. Here we see that there is a steady increase in the probability of controllers incurring a LoS as the time since the start of their shift increases.

The Hosmer and Lemeshow test shows that there is insufficient evidence to suggest that the model does not fit for LoS ($\chi^2_{(7)}$=.79, p=1.00 > .05) or RI ($\chi^2_{(7)}$=.1.08, p=.1.00 > .05). This in turn implies that all of the tests' assumptions were met, namely; dichotomous dependent variable, interval independent variable (assumed linearity) and a model that fits.

The second research question asked what event variables and demographics are common between events. When grouped into shift times (6:00 – 13:00, 13:01-20:00 and

20:01-05:59 South African times and 8:00 – 15:00, 15:01 – 22:00 & 22:01 – 07:59 UTC), frequencies show that events most frequently occur in the first shift (8:00 – 15:00 UTC) with a frequency of 46 of the 78 reports (59%), followed by the third shift (22:01 – 07:59 UTC) reported in 20 of the events (26%) and lastly the second shift time reported in 12of the reports (15%). This result shows that the first shift (6:00 – 13:00 Central African time) is the most at risk shift of incurring a safety event. When the data is grouped into time periods of an hour, the most frequent occurring time is 12:01 – 13:00 UTC (*f=12*), followed by 05:01 – 06:00 UTC (*f=8*) and 10:01 – 11:00 UTC (*f=8*). This shows that the most at risk time is 12:01 and 13:00 UTC which fall in the last hour of the first shift. The next most at risk times fall between 05:01 UTC and 06:00 UTC as well as 10:01 UTC and 11:00 UTC.

The most frequent occurring type of weather is reported as undefined in the reports (*f=40*), with 'clear' as the next most frequent occurring (*f=19*) followed by Instrumental Meteorological Conditions (*f=11*). The most common occurring sector was reported as aerodrome and approach combined (*f=20, 21.3%*), followed by approach (*f=15, 16.00 %*).

The most frequent occurring severity level of the incident scored by the rating scale (figure 2) was minimal (f=21, 27%) followed closely by marginal (f=20, 26%) and significant (f=19, 24%). Of the 78, only seven were rated as severe (*f=7, 9%*). Descriptive statistics show that the average number of aircraft on radio frequency at the time of safety events is 8 ($\bar{x} = 8.32, SD = 6.566$), with the most common occurring number of aircraft on frequency set at 2 (Mo = 2). The average movement per hour was 29.45 ($\bar{x} = 29.45, SD = 15.215$) with the most frequency set at 42 ($Mo = 42$). Analysing the statistical frequencies, it can be seen that 22 of the 44 reported movements per hour (50%) were above 30 movements per hour. Recall that the ATM capacity document sets maximum capacity at 30 movements per hour. This shows that 50% of the reported movements per hour were above maximum capacity levels.

When evaluating the combination of sectors, cross tabulation showed that aerodrome and approach sectors were combined in two instances, with more than 30 movements per hour, tower west and east combined once and radar west and east sectors combined four times with traffic volumes of more than 30 movements per hour. This implies that 7 of the 22 (31.82 %) occurrences of more than 30 movements per hour occurred on combined sectors.

Of the 93 controllers investigated, 72 were male (77.40%) and 21 were female (22.60%). In order to see the relevance of these findings, they must be placed in context of the employee demographics of controllers in South Africa. Of the 355 ANSP employees in 2013, 254

(71.5%) were male and 101 (28.5%) were females. Within the ANSP staff, 28.35% of the males were involved in an event whilst 20.79% of the females were involved in safety events. As only access to the demographics from 2013 was given, the percentages cannot be taken as absolutes but rather as indications of the ratio of men and women involved in events. The percentages show that a greater percentage of men are involved in safety events.

The most common occurring English proficiency was level 6 with 1 controller reported at level 4, 29 at level 5, and 64 at level 6. The mean age of the controllers involved in the events is 32.40 with $\times \sim N\ (32.40,\ 5.44^2)$ and a minimum age of 21 and maximum of 52. In 2013, ANSP staff ages ranged from 22 to 63, with a mean age of 33.66, $\times \sim N\ (33.66,\ 8.27^2)$. These mean ages mirror the mean ages of controllers involved in the safety events. Logistic regression showed that none of the demographic variables (age, gender and language proficiency) are significant predictors of either RI ($\chi^2_{(4)} = 8.30$, $p=.08 > .05$) or LoS ($\chi^2_{(4)} = 8.30$, $p=.08 > .05$).

4.3. Safety Events

The analysis was performed with respect to the two types of safety events; a LoS and a RI in order to establish whether different human factors were associated to different event types. If it was established that the variable in question was a predictor of both RI and LoS, then subsequent analyses were performed on the variable labelled ‘event type’ which included both RI and LoS.

The next question asked which human factors are associated with safety events. Cluster analyses were performed on the human factors variables that had more than three component variables. This method was adopted in order to focus the research by amalgamating similar component variables into fewer representative variables. Recall that a hierarchical cluster analysis is a means of investigating grouping in data (MathWorks, 2013) which starts with each object representing an individual cluster which are subsequently merged according to their similarity (Mooi & Sarstedt, 2011). In this way, the component variables under the human factors variables with more than 3 component variables were clustered into groupings so as to minimise the number of component variables. Once the clusters were established, the variables were recoded. This meant that, for example, information processing was coded from 1 to 4 (1 representing detection of information errors, 2 representing interpretation, 3 representing visual errors and four auditory). This ultimately allowed for the amalgamation of similar variables so as to compress many variables to fit under one. This allowed each variable to be entered into a cluster analysis with other human factors and the Los and RI variables.

Table 5. Variables and component variables pre cluster analysis.

	Information Processing	**Situation Awareness**	**Memory**
Component variables	• Monitoring failure • Failure to scan runway • Similar call signs • Information Overload • Misjudged Aircraft projection • Error in Auditory detection • Ambiguous instructions issued • Incorrect detection of visual information	• Erroneous Perception • Erroneous hear-back • Misjudged aircraft projection • Instruction issued to wrong aircraft • Failure to recognize risk	• Forgot planned action • Inaccurate recall of temporary memory • Rarely used information • Working memory failure
	Attention	**Human Machine Interface**	**Workload**
Component variables	• Divided • Selective • Focused • Sustained • Vigilant	• Poor label management • System delay • Insufficient use of tools • Poor radar images	• High complexity • Low Complexity • High volume • Low volume • Underload • Overload • Subjective traffic complexity rating • Subjective workload rating

The variables with more than three component variables (Table 5) included information processing (8 component variables), situation awareness (5 component variables), memory (4 component variables), attention (5 component variables), human-machine interface (4 component variables) and workload (8 component variables). The clusters of these human factors variables were decidedly interpretable in that majority of the cluster breaks and clusterings were clear and easily translated. The summary of clusters chosen under each variable is presented in Table 6. The table shows the number of clusters that the agglomeration schedule alluded to, the number of clusters chosen and what those clusters were. The symbol '≈' denotes approximation. The remaining human processing variables that had 2 or less sub-components were recoded into one variable.

Table 6. Summary of the human factors clusters.

	Information Processing	**Situation Awareness**
No of Clusters suggested	4	≈ 3
No of cluster chosen	4	4
Clusters	Quality of information received Interpretation Visual detection errors Auditory detection errors	Communication Situation Assessment Perception Distraction
	Attention	**Memory**
No of Clusters suggested	≈ 2	3
No of cluster chosen	2	3
Clusters	Vigilance Divided	Forgot Action Working memory Rarely used info
	Human Machine Interface	**Workload**
No of Clusters suggested	≈ 1	4
No of cluster chosen	2	4
Clusters	System System Use	Overload Underload Subjective rating of workload Complexity

Nine sub-variables under the *human factors* heading were entered into the cluster analysis with the LoS variable. These sub-variables included; information processing cluster, situation awareness cluster, attention cluster, workload cluster, memory cluster, human machine interface cluster, mental alertness, mental models and the decision making cluster. According to the agglomeration schedule (Table 7), breaks occur at greatly increased distance levels around 4 clusters (*d=3.25*). The 5th cluster's coefficient (10.25) lies higher than the recommended Euclidean distance of 9.00, suggesting that between 3 and 4 clusters should be chosen. As the first increased break lies at the 4th cluster, 3 clusters most adequately explain the data.

Table 7. Agglomeration Schedule for human factors with LoS.

Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	1	10	.00	0	0	6
2	2	5	.50	0	0	3
3	2	8	2.00	2	0	4
4	2	7	5.25	3	0	6
5	4	6	10.25	0	0	7
6	1	2	15.50	1	4	9
7	3	4	21.17	0	5	8
8	3	9	27.75	7	0	9
9	1	3	60.80	6	8	0

The dendrogram's 'clusters combined' column (figure 10) and Agglomeration Schedule (Table 6) show that mental models and LoS were clustered together in the first stage, followed by attention with decision-making, human machine interface and memory variables. Workload was clustered with situation awareness, information processing and mental alertness variables in the final stages. Three clusters were chosen as the best descriptors of the data. These three clusters chosen were; (a) mental models and Los, (b) decision making, attention, human-machine interface and memory and (c) situation awareness, workload, information processing and mental alertness. A logistic regression analysis (Table 8) run with mental models (covariates) and LoS (dependent variable) showed that there was insufficient evidence to suggest that mental models are a significant predictor of LoS ($\chi^2_{(1)}$=1603, p= .21 > .05).

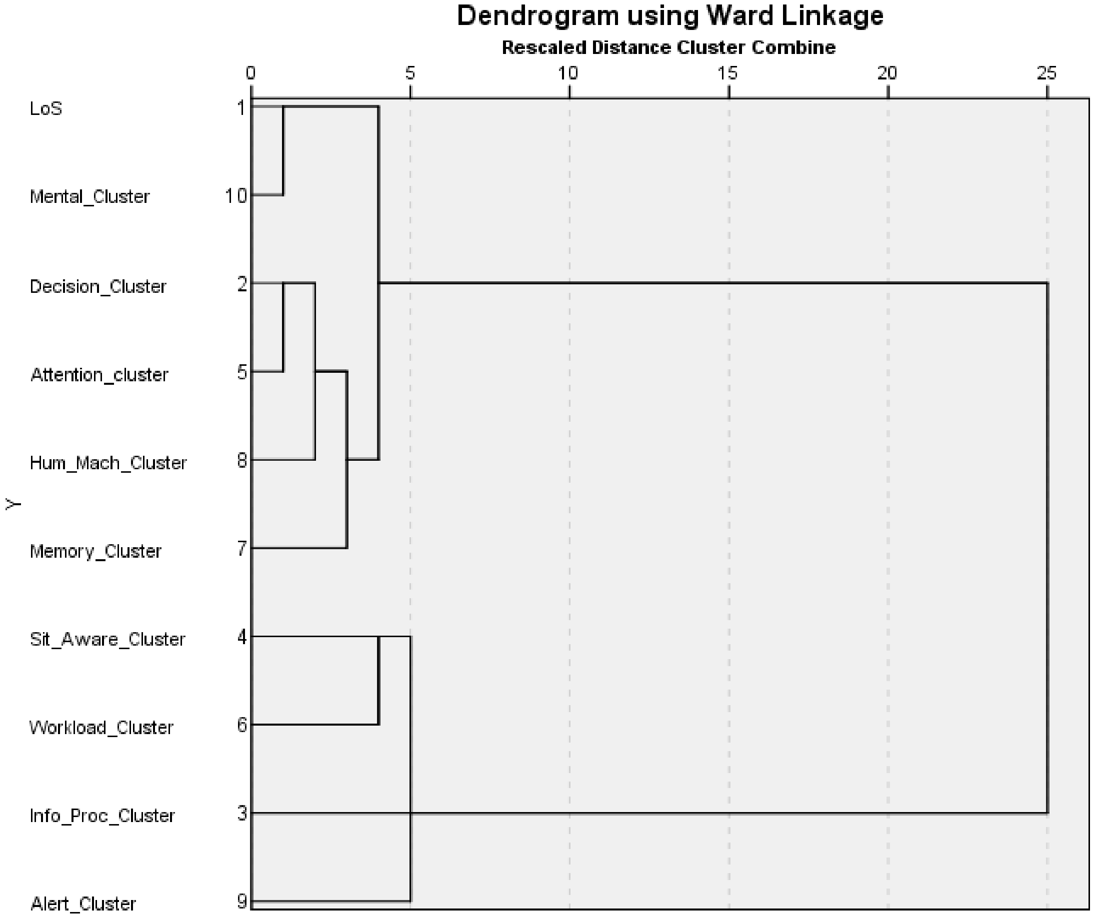


Figure 10. Dendrogram using Ward linkage to cluster human factors with LoS.

Table 8. Logistic regression between LoS and mental models

Variable	Significant	Beta	Direction	Odds Ratio	Confidence Interval
Mental Models	X (p=.22)	-.79	-ve	.46	.13 → 1.60

The same nine variables were then entered into a cluster analysis with the RI variable. The agglomeration schedule (Table 9) shows that breaks occur at greatly increased distance levels at stage 4 (d= .75) suggesting that 3 clusters best describe the data. Again mental models are clustered with Runway Incursions in the first level, whilst attention, human machine interface, decision making and mental alertness are clustered together in subsequent stages. Situation awareness, workload and information processing are then clustered together and only in the final stages are mental models clustered with decision making (figure 11). The clusters are thus similar to the previous analysis for LoS in that they were; (a) mental models and RI, (b) decision making, attention, human-machine interface and mental alertness and (c) situation awareness, workload and information processing. A logistic regression (Table 9) analysis run on mental models and RI showed that there was insufficient evidence to suggest that mental models are a predictor of RI ($\chi^2_{(1)}$= 2.756, p= .10 > .05).

Table 9. Agglomeration schedule for human factors with RI.

Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	3	9	.00	0	0	2
2	3	6	.00	1	0	5
3	5	10	.00	0	0	4
4	5	8	.75	3	0	5
5	3	5	1.75	2	4	8
6	2	4	3.00	0	0	7
7	1	2	5.33	0	6	9
8	3	7	9.62	5	0	9
9	1	3	29.10	7	8	0

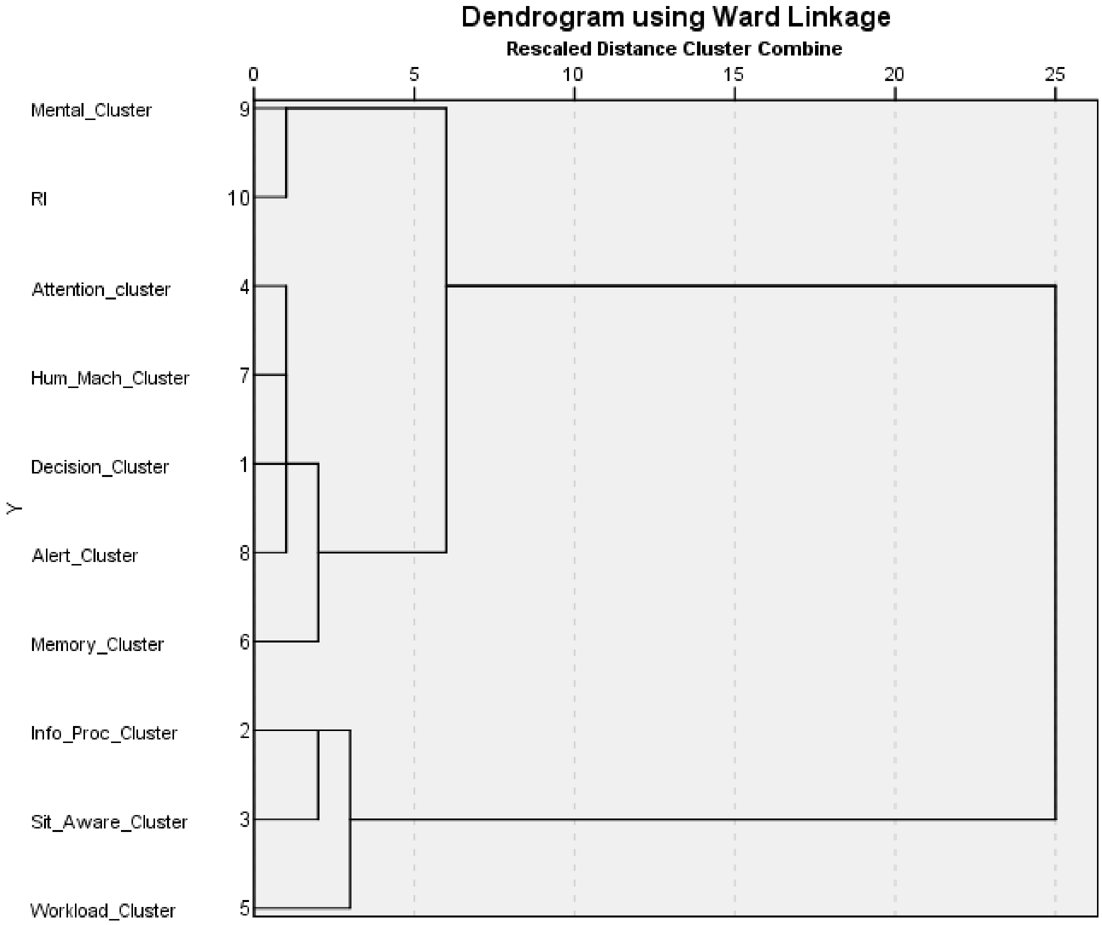


Figure 11. Dendrogram using Ward linkage to cluster human factors with RI.

Table 10. Logistic regression with Mental Models and RI.

Variable	Significant	Beta	Direction	Odds Ratio	Confidence Interval
Mental Models	X (p= 3.00)	1.01	+ve	3.00	.76 → 11.88

Logistic regression analyses were then run on the human factors variables individually (covariates) with both LoS and RI (dependent variables). These had to be entered separately as entering all nine variables at once required more cases than were present in the data. When entered in together, the model could not be fitted because the number of observations is less than or equal to the number of model parameters. The analysis (Table 11) showed that information processing is the only predictor of both LoS and RI ($\chi^2_{(3)}$=27.44, p=.00 & $\chi^2_{(3)}$=28.62, p=.00). When a logistic regression was run on the individual human factors variables and event type variable (both RI and LoS coded into one variable), information processing was again the only significant predictor ($\chi^2_{(1)}$=24.55, p=.00).

Table 11. Summary of logistic regression on information processing (covariate) and events (dependent).

Variable	Significant	Beta	Direction	Odds Ratio	Confidence Interval
Information Processing Errors	✓ (p=.001)	2.27	+ve	9.67	2.594 → 36.070

The more information processing errors an individual displays, the more likely a safety event will occur ($\beta_1 > 0$). Controllers with poor information processing skills are 9.67 times more likely to cause a safety event . However, the large confidence interval (2.59 to 36.07) reflects a possible overestimation that might be related to the small number of observations for information processing as an explanatory variable (Nemes, Jonasson, Genell & Steineck, 2009).

In terms of the assumptions of the test, the Hosmer and Lemeshow test indicates that there is insufficient evidence to suggest that the model does not fit ($\chi^2_{(2)}$=1.98, p=.371).

The individual factors of information processing (detection errors, interpretation errors and errors in perceptual and auditory detection) were entered into a logistic regression with both

LoS and RI respectively and there was sufficient evidence to suggest that at least one of these factors predicted both LoS ($\chi^2_{(3)}$=24.55, p=.00 < .05) and RI ($\chi^2_{(3)}$=27.44, p=.00 < .05). Interpretation errors and auditory detection errors were significant predictors of both LoS and RI (Table 12). Controllers exhibiting interpretation errors are 46 times more likely to incur a RI and 6.53 times more likely to incur a LoS. However, these results regarding interpretation errors should be treated with caution due to the large confidence intervals associated with them. Controllers displaying difficulties in auditory detection are 33.5 times more likely to incur a LoS and 68 times more likely to incur a RI. Once again, however, the confidence intervals are very large indicating that other factor might have been responsible for the predictions. Following these predictions, it can be seen that interpretation errors auditory detection errors predict both LoS and RI.

Table 12. Logistic regression with information processing components (covariates) and safety events (dependent variable).

Variable	**Predicted variable**	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Quality of Information received	Los	X (p=1.00)	-21.20			
	RI	X (p=1.00)	21.21			
Interpretation errors	Los	✓ (p=.00)	1.88	+ve	6.53	1.32 → 32.32
	RI	✓ (p=.00)	3.83	+ve	46.00	5.17 → 409.38
Visual detection errors	Los	X (p=1.00)	-21.20			
	RI	X (p=1.00)	21.203			
Auditory detection errors	Los	✓ (p= .00)	3.51	+ve	33.50	2.63 → 180.25
	RI	✓ (p=.00)	4.22	+ve	68.00	7.6 → 601.44

The next question asked which external factors are associated with safety events. Seven external variables were entered into the cluster analysis with LoS and RI respectively to establish which external variables clustered around safety events. These variables included recreational flights in the airspace, airspace design, complex traffic scenarios, workplace design, distracting phone calls, weather phenomena and combined sectors. The agglomeration schedule (Table 13) showed that one cluster best explains the data (*d=9.5*). The first stage of the analysis saw recreational flights in the airspace clustered with airspace design. The LoS variable was only clustered in the last stage and is thus not significant.

Table 13. Agglomeration schedule for external factors with LoS.

Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	4	7	9.00	0	0	3
2	2	5	18.50	0	0	4
3	4	6	32.17	1	0	6
4	1	2	49.33	0	2	5
5	1	3	68.42	4	0	6
6	1	4	89.71	5	3	7
7	1	8	129.50	6	0	0

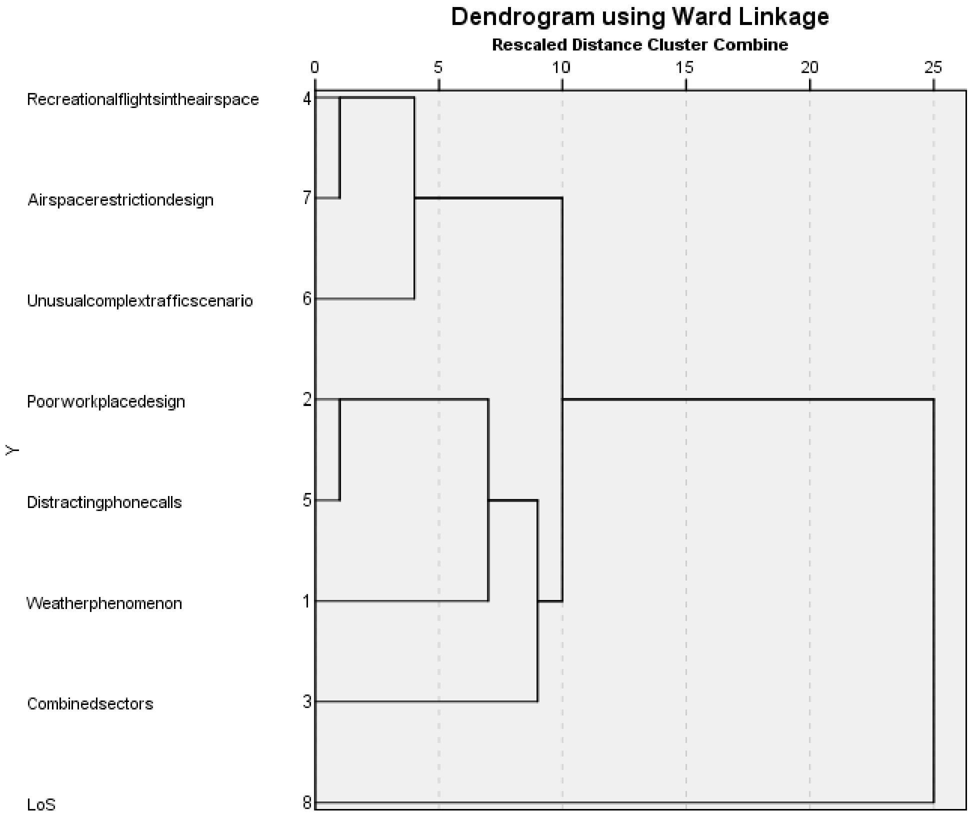


Figure 12. Dendrogram using Ward linkage to cluster external factors with LoS.

Logistic regression analyses showed that there was sufficient evidence to suggest that at least one of the external factors (Independent variables) is a predictor of LoS at the 5% level of significance ($\chi^2_{(7)}$=17.56, p=.01 < .05). Analysis of the variables in the equation (Table 14) showed that poor workplace design ($\chi^2_{(1)}$=6.00, p=.01< .05) is a significant predictor of LoS, with airports with poor workplace design 7.8 times more likely to cause an LoS. However, the confidence intervals is fairly large. The Hosmer and Lemeshow test shows that there is insufficient evidence to suggest that the model doesn't fit ($\chi^2_{(8)}$= 3.74, p=.88 > .05).

Table 14. Logistic regression external factors (covariates) and LoS (dependent).

Variable	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Poor workplace design	✓ (p=.01)	2.06	+ve	7.81	1.51 → 40.44
Combined sectors	X (p= .58)	.47			
Recreational flights in airspace	X (p=1.00)	-19.42			
Distracting phone calls	X (p=1.00)	-.001			
Unusual complex traffic scenario	X (p=.64)	-.37			
Airspace restriction	X (p=.51)	-.65			
Weather Phenomenon	X (p=.28)	1.01			

The same variables (covariates) were then entered into a cluster analysis with RI (dependent variable). The agglomeration schedule (Table 15) showed that the largest distance break occurs at the 4th stage (*d=1.67*) suggesting that three clusters best explained the data. Again, the first stage clustered recreational flights with airspace design in the Dendrogram (figure 13). The next stage clustered weather phenomena with complex traffic scenarios. The following two stages cluster workplace design with combined sectors and Runway Incursions. The three clusters were thus; (a) recreational flights and airspace design, (b) weather phenomena and complex traffic scenarios and (c) workplace design, combined sectors and Runway Incursions.

Table 15. Agglomeration schedule for external factors with RI.

Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	4	7	1.00	0	0	5
2	1	6	2.00	0	0	6
3	2	3	3.00	0	0	4
4	2	8	4.67	3	0	7
5	4	5	7.00	1	0	6
6	1	4	10.27	2	5	7
7	1	2	21.88	6	4	0

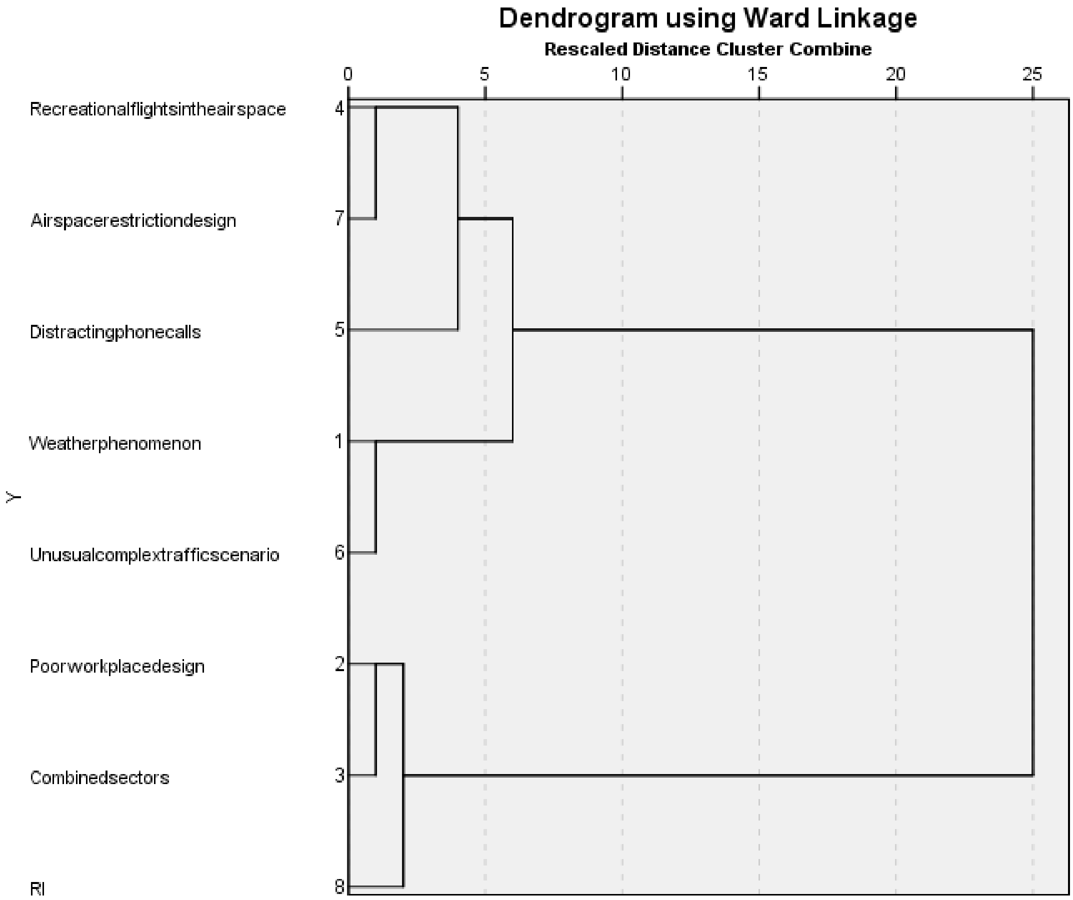


Figure 13. Dendrogram using Ward linkage to cluster external factors with RI.

The same seven external factors were entered into a logistic regression using RI as the dependent variable. There was sufficient evidence to suggest that at least one of the external factors is a predictor of RI at the 5% level of significance ($\chi^2_{(7)}$=19.11, p=.01 < .05). Analysis of the variables in the equation (Table 16) showed that workplace design is a predictor of RI ($\chi^2_{(1)}$=10.29, p=.0 < .05). The odds ratio shows that poor workplace designs are 9.95 times more likely to incur RI, but the confidence interval is once again fairly large.. The Hosmer and Lemeshow test shows that there is insufficient evidence to suggest that the model doesn't fit ($\chi^2_{(8)}$=6.25, p=.62 > .05).

Table 16. Logistic regression external factors (covariates) and RI (dependent).

Variable	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Poor workplace design	✓ (p=.01)	2.29	+ve	9.95	2.44 → 40.49
Combined sectors	X (p= .35)	-.83			
Recreational flights in airspace	X (p=1.00)	19.53			
Distracting phone calls	X (p=.84)	-.19			
Unusual complex traffic scenario	X (p=.74)	.27			
Airspace restriction	X (p=.63)	.50			
Weather Phenomenon	X (p=.42)	-.77			

The components of workplace design; physical set up and staffing procedures were entered as covariates into a logistic regression with Los and RI (dependent variable). The omnibus test of model coefficients showed that at least one of the covariates (staffing and physical design) predicted LoS ($\chi^2_{(3)}$=9.66, p=.02 < .05) as well as RI ($\chi^2_{(3)}$=11.30, p=.01 < .05).

Table 17. Logistic regression with workplace design components (covariates) and safety events (dependent variable).

Variable	Predicted variable	Significant	Beta	Direction	Odds Ratio	Confidence Interval
Poor physical workplace design	LoS	✓ (p=.00)	1.98	+ve	7.27	1.89 → 27.96
Poor workplace Staffing design		X (p=.30)	19.89			
Poor physical workplace design	RI	✓ (p=.00)	1.97	+ve	7.20	1.94 → 26.70
Poor workplace staffing design		X (p=.22)	-19.87			

Physical workplace design (Table 17) showed to be a significant predictor of both RI and LoS, with airports with poor physical workstation setting 7.27 times more likely to incur a LoS and 7.20 times more likely to incur a RI. Both show significant confidence intervals, suggesting that physical workplace design may not be predicting of safety events as strongly as suggested by the odds ratios.

The next question concerned which risk factors are related to the events. Logistic regression was performed on risk factors with event type as the dependent variable. Risk factors include failure to respond to alerts, unclear position takeover, poor co-ordination standards, pilot controller communication, failure to pass essential traffic information, poor R/T phraseology use and lack of memory cues in the environment. It was shown that at least one risk factor predicted LoS ($\chi^2_{(7)}$=25.21, p=.00 < .05) and RI ($\chi^2_{(7)}$=28.17, p=.00 < .05). Analysis of the variables in the equation (Table 18) shows that poor adherence to co-ordination standards ($\chi^2_{(1)}$=3.81, p=.05 < .05) as well as lack of memory cues in the environment ($\chi^2_{(1)}$=8.00, p=.01 < .05) are significant predictors of safety events. The direction of the betas and odds ratios suggested that controllers displaying poor adherence to co-ordination standards are 16.26 times more likely to incur a LoS and stations that lack a memory cue are 15.05 times more likely to incur a RI. It is noted again that there is a possibility of overestimation as reflected in the large confidence intervals. Poor adherence to communication standards was shown to be an insignificant predictor of RI with an odds ratio of .05 and confidence interval of 1.01. A lack of memory cue in the environment showed to be a poor predictor of LoS with an odds ratio of .08 and confidence interval of only .46. Hosmer and Lemeshow tests show that there was not sufficient evidence to suggest that this model does not fit ($\chi^2_{(7)}$=3.58, p=.83 > .05). These results show that poor coordination standards are a strong predictor of a LoS, whilst a lack of memory cues are a strong predictor for RI.

Table 18. Logistic regression risk factors (covariates) and event type (dependent).

Variable	**Predicted variable**	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Failure to respond to alerts	LoS	X (p=.55)	.71			
	RI	X (p=.79)	-.34			
Unclear position takeover	LoS	X (p=.63)	-.66			
	RI	X (p=.50)	1.01			
Poor co-ordination standards	LoS	✓ (p=.05)	2.79	+ve	16.26	1.01 → 259.88
	RI	✓ (p=.05)	-3.00	-ve	.05	.00 →1.01
Pilot controller communication	LoS	X (p=.61)	-.46			
	RI	X (p=.44)	.78			
Failure to pass essential traffic information	LoS	X (p=.30)	.84			
	RI	X (p=.27)	-1.32			

Poor R/T phraseology	LoS	X (p=.10)	- 1.30			
	RI	X (p=.08)	1.47			
Lack of memory cues in the environment	LoS	✓ (.01)	- 2.48	-ve	.08	.02→ .48
	RI	✓ (.01)	2.71	+ve	15.05	2.30 → 98.62

The next question asked which stated primary causal errors related to events. A logit regression was run on stated causal errors (covariates) and event type (dependent variable). The stated causal errors included memory lapse, mishear of read-back, incomplete clearances issued, incorrect timing in issuing of clearances, misjudging aircraft, radar and visual monitoring failure, incorrect assumptions regarding separation, and instructions issued to the wrong aircraft. Logistic regression showed that at least one stated causal error is a significant predictor of LoS, ($\chi^2_{(8)}$=30.91, p=.00 < .05), analysis of the variables in the equation showed that four factors are significant predictors of LoS; incomplete clearances issued, misjudging aircraft, radar and visual monitoring failures and incorrect assumptions regarding separation (Table 19). Misjudged aircraft projections shows to be a weak predictor of LoS with an odds ratio of 8.25 and a large confidence interval. The same can be said for incorrect assumption regarding separation which shows a small odds ratio of .07 and a small confidence interval of .76. Following this, it can be said that there are two stated causal errors that are strong significant predictors of LoS, namely; incomplete clearance issues and radar and visual monitoring failures. Controllers issuing incomplete clearances are 13.86 times more likely to incur a LoS and controllers that make incorrect assumptions regarding separation are 10.59 times more likely to incur a LoS. However, the confidence intervals are extremely high, indicating that caution is needed in interpreting these odds ratios.

Three out of these four errors are rooted in the interpretation or situation assessments, which, according to Reason’s representation of human error (figure 3) correlate to knowledge-based mistakes. It would thus be expected to find that knowledge based mistakes predict these errors.

Table 19. Logistic regression on causal errors and LoS.

Predictor	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Incomplete clearances issued	✓ (p=.03)	2.63	+ve	13.86	1.32 → 145.51
Misjudged aircraft projections	✓ (p=.05)	2.11	+ve	8.25	1.02 → 66.54
Radar and visual monitoring failure	✓ (p=.03)	2.36	+ve	10.59	1.28 → 89.91
Incorrect assumption regarding separation	✓ (p=.03)	-2.66	-ve	.07	.01 → .77

Logistic regression showed that at least one stated causal error is a significant predictor of RI, ($\chi^2_{(8)}$=44.70, p=.00 < .05), and analysis of the variables in the equation showed that only two causal factors; incomplete clearance issues and radar and visual monitoring failures are significant predictors of RI (Table20). The odds ratios and confidence intervals show that neither incomplete clearance issues nor radar and visual monitoring failures are strong predictors of RI. The confidence intervals of only .42 and .70 respectively indicate that one can be fairly confident about the accuracy of the odds ratios. This leads to the conclusion that there are no causal errors that boast strong prediction of RI.

Table 20. Logistic regression on causal errors and RI.

Predictor	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Incomplete clearance issues	✓ (p=.02)	-5.23	-ve	.01	.00 →.42
Radar and visual monitoring failures	✓ (p=.02)	-3.80	-ve	.02	.00 → .70

The results for the analysis with respect to safety events are summarised in Table 21. This constitutes the ‘first step’ in the analysis, whereby the factors are investigated in terms of their relation to safety events.

Table 21. Summary of findings from ‘step one’.

Safety event type	Predictor	Predictor type
RI	Time since start of shift	Shift event
	Interpretation errors	Human Factor
	Lack of memory cues	Risk Factor
LoS	Time since start of shift	Shift event
	Auditory detection errors	Human Factor
	Poor workplace design	External Factor
	Poor coordination standards	Risk Factor
	Incomplete clearance issues	Causal error
	Radar and visual monitoring	

4.4. Human Error

The next question asked which human errors are related to human factors. The same 9 human factors that were used in the first stage (information processing cluster, situation awareness cluster, attention cluster, workload cluster, memory cluster, human machine interface cluster, mental alertness, mental models and the decision making cluster) were entered into a cluster analysis with the human error types (knowledge based mistakes, rule based mistakes, lapses and slips). The agglomeration scale (Table 22) showed the first largest break around stage 4 or 5, suggesting that 3 or 4 clusters best explained the data. The Dendrogram showed knowledge based mistakes clustered with attention and decision making, rule based mistakes clustered with lapses and human-machine interface, and slips clustered with mental models and memory. The three chosen clusters were thus (a) knowledge based mistakes, attention and decision making, (b) rule based mistakes, lapses and human-machine interface, (c) mental models, memory and mental alertness and (d) situation awareness, workload and information processing.

Table 22. Agglomeration schedule for human factors with human errors.

Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	1	7	.00	0	0	3
2	2	10	.50	0	0	4
3	1	13	1.17	1	0	6
4	2	3	2.67	2	0	6
5	4	12	4.67	0	0	7
6	1	2	7.33	3	4	9
7	4	9	10.67	5	0	9
8	6	8	17.17	0	0	10
9	1	4	24.28	6	7	11
10	5	6	31.78	0	8	12
11	1	11	40.60	9	0	12
12	1	5	91.08	11	10	0

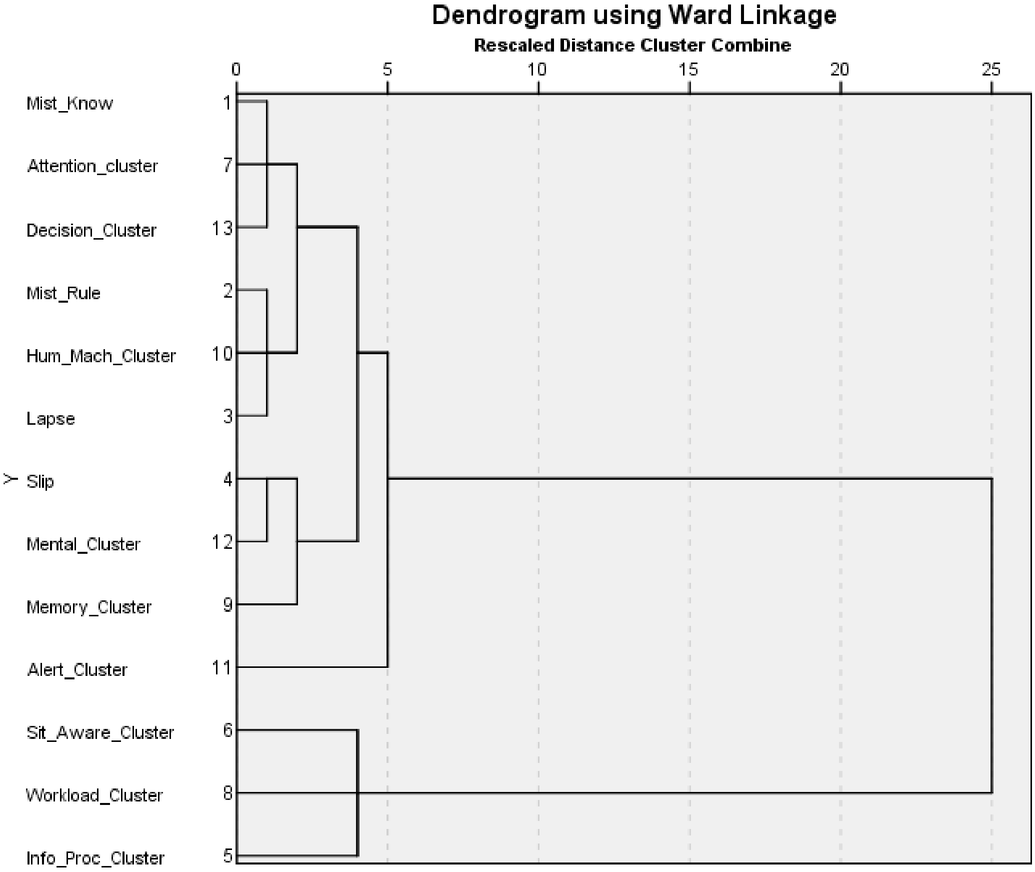


Figure 14. Dendrogram using Ward linkage to cluster human factors with human errors.

Logistic regression showed that there was insufficient evidence to suggest that knowledge based mistakes predicted errors in attention ($\chi^2_{(1)}$=.00 , p=.99 > .05) or decision-making ($\chi^2_{(1)}$=.101, p=.75 > .05). Further logistic regression analyses showed that there was insufficient evidence to suggest that rule based mistakes predict human machine interface errors at the 5% level of significance ($\chi^2_{(1)}$=1.03, p=.31 > .05) nor do lapses ($\chi^2_{(1)}$=.14, p=.71 > .05). Lastly, logit regression showed that there was insufficient evidence to suggest that slips predict errors in mental models ($\chi^2_{(1)}$=.35, p=.55 > .05) or memory ($\chi^2_{(1)}$=.01, p=.94 > .05) at the 5% level of significance.

When the components of information processing (detection of information, interpretation, visual and auditory errors) were entered into logistic regressions with the four primary error types (knowledge and rule based mistakes, slips and lapses) it was shown that lapses are predictors of both interpretation errors ($\chi^2_{(1)}$=6.193, p=.013) and auditory detection errors ($\chi^2_{(1)}$=9.79, p=.00 > .05). The odds ratios and Beta values (Table 23) showed controllers who experience lapses are 8.15 times more likely to experience auditory detection errors and 7.5 times more likely to incur interpretation errors whilst controlling. Again, however, the confidence intervals are high indicating that caution should be exercised in interpreting these results.

Table 23. A summary of the logistic regression on information processing factors and error types.

Variable	**Predictor**	**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Quality of information received	None	X				
Interpretation errors	Lapse	P= .013	2.02	+ve	7.5	1.534 → 36.66
Visual detection errors	None	X				
Auditory detection errors	Lapse	P=.002	2.10	+ve	8.15	2.19 → 30.31

The next question asked which human errors are related to external factors. The four human error variables were entered separately into a logit regression with the same seven external factor variables used in the previous analyses (recreational flights in the airspace, airspace design, complex traffic scenarios, workplace design, distracting phone calls, weather phenomena and combined sectors). At least one external factor was shown to be a significant predictor of lapses ($\chi^2_{(7)}$=16.180, p=.024) but no other human errors. When evaluating the variables in the equation, workplace design was the only significant predictor ($\chi^2_{(1)}$=8.82, p=.00 < .05). The Beta ($\beta = -2.45 < 0$) and odds ratio (.09) indicated that organisations with poor workplace (both physical and staffing) design are only .09 times more likely to incur lapses in controllers than organisations with adequate workplace design. The odds ratio and confidence interval of .42 show that workplace design is not a strong predictor of lapses. The Hosmer and Lemeshow test showed that there was insufficient evidence to suggest that the model does not fit ($\chi^2_{(8)}$=3.78, p=.88 > .05). When the components of workplace design (physical setting and staffing procedures) were entered into a regression it was found again that physical workplace design was the only significant predictor of lapses ($\chi^2_{(1)}$=18.11, p=.00 < .05). The Beta ($\beta = 2.92 < 0$) and odds ratio of 18.53 showed that poor workplace designs are strong predictor of lapses. The confidence interval (4.54 → 75.64) is large, indicating that caution should be exercised in interpreting the results.

Cross tabulation showed that 34.5 % of recorded poor workplace designs occurred within combined aerodrome and approach sectors, followed by 17.2% in Radar West and East combined. They also showed that 46.4% of reported poor workplace designs occurred in International Airport X, followed by 14.3% at International Airport Y.

The following question asked which human errors predict safety events. When clustering event type (LoS and RI) with error types (knowledge and rule based mistakes, slips and lapses), the squared Euclidean distance showed that only one cluster should be used but it is interesting to note that lapses, rule based mistakes and knowledge based mistakes clustered with RI, whilst LoS clustered with slips. The Euclidean distance past the second stage (d= 20.67) was above the recommended level of 9.00.

When a logit regression was run on event type and the four error types there was sufficient evidence to suggest that one of the error types is a predictor safety events ($\chi^2_{(4)}$=19.48, p=.00 < .05) (Table 24). Lapses were reported as a significant predictor of safety events ($\chi^2_{(1)}$=16.97, p=.00 < .05). Controllers who have lapses are 21.56 times more likely to cause a safety event. However, the confidence interval is high and therefore caution needs to be exercised in interpreting this result.

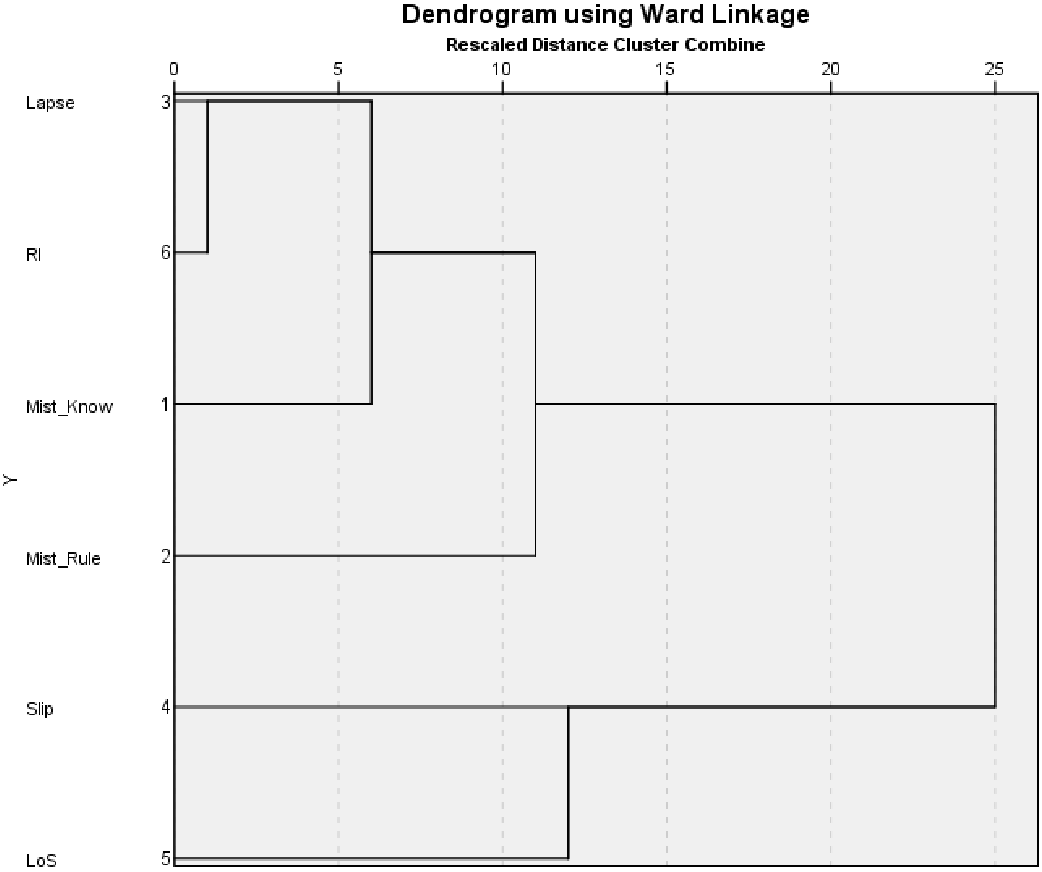


Figure 15. Dendrogram using Ward linkage to cluster human errors with LoS and RI.

Table 24. A summary of the logistic regression on event type (dependent variable) and error types (covariates).

Predictor	Significant	Beta	Direction	Odds Ratio	Confidence Interval
Lapse	✓ (p=.00)	3.07	+ve	21.56	5.00 → 92.95
Rule based mistakes	X (p=.12	1.69	+ve	5.40	.66 → 44.02
Knowledge based mistakes	X (p=.97)	.03	+ve	1.03	.20 → 5.22
Slip	X (p=.13)	1.21	+ve	3.37	.69 → 16.37

Logistic regression run on the human error types (covariates) and LoS (dependent variable) and RI (dependent variable) respectively, there is sufficient evidence to suggest that at least one of the covariates is a predictor of both LoS ($\chi^2_{(4)}$=18.09, p=.00 < .05) and RI ($\chi^2_{(4)}$=19.48, p=.00 < .05). Analyses of the variables in the equation show that lapses predict both LoS and RI. Controllers experiencing lapses are 17.73 times more likely to incur a LoS. The odds ratio (.05) shows that lapses are not strong predictors of RI.

Table 25. Logistic regression with lapses (covariates) and safety events (dependent variable).

Predictor		**Significant**	**Beta**	**Direction**	**Odds Ratio**	**Confidence Interval**
Lapse	LoS	✓ (p=.00)	2.88	+ve	17.73	4.23 → 73.14
	RI	✓ (p=.00)	-3.07	-ve	.05	.01 → .20

The next question concerned which human errors are related to the stated causal errors. A logit regression was run on human errors (covariates) and stated causal errors (dependent variable). Stated causal errors included memory lapse, mishear of read-back, incomplete clearances issued, incorrect timing in issuing of clearances, misjudging aircraft, radar and visual monitoring failure, incorrect assumptions regarding separation, and instructions issued to the wrong aircraft. Logistic regression revealed that rule based mistakes are predictors of assumption, with individuals displaying rule based mistakes 2.5 times more likely to make assumptions regarding separation. Slips are shown to predict radar and visual monitoring failures, misjudging aircraft projection, incorrect timing of clearances and memory lapses. A slip is 2.77 times more likely to lead to incorrect assumptions regarding separation, 2.85 times more likely to lead to misjudging aircraft positions, 7.58 times more likely to lead to incorrect timing in issuing clearances and 2.61 times more likely to incur a memory lapse. Knowledge based mistakes were reported as a predictor of visual and monitoring failures, although the odds ratio of .15 shows that this is a weak prediction. Knowledge based mistakes were shown to predict incomplete clearance issues and mishear of read-back. The analyses show that knowledge based mistakes are 5.96 times more likely to be associated with incomplete clearances and 4.74 times more likely to be associated with mishearing read-back.

Table 26. A summary of the logistic regression on causal errors and human errors.

Covariates	**Predictor**	**Significant**	**B (direction)**	**Odds Ratio**	**Confidence Interval**
Assumption	Rule-based mistakes	✓ (p= .05)	.91	2.49	1.01 → 6.15
Radar and visual monitoring failure	Slips	✓ (p= .02)	1.01	2.77	1.15 → 6.67
	Knowledge-based mistakes	✓ (p= .01)	-1.88	.15	.04 → .58
Incomplete clearances issued	Knowledge-based mistakes	✓ (p= .00)	1.78	5.96	1.78 → 19.95
Misjudging aircraft	Slip	✓ (p=.02)	1.05	2.85	1.18 → 6.84
Incorrect timing in clearance issue	Slip	✓ (p=.00)	2.02	7.57	2.79 → 20.56
Mishear Read-back	Knowledge based mistake	✓ (p=.01)	1.56	4.74	1.46 → 15.35
Memory lapse	Slip	✓ (p=.04)	.96	2.61	1.03 → 6.60

4.4. Summary of results

The findings can be consolidated by summarizing significant findings under each broad research question. It was found that time since start of shift is a significant predictor of safety events. Furthermore, time frames 0-30 minutes and 91 – 151 minutes were the most frequently occurring time of the safety events. In terms of safety events, it was found that information processing (human factors), workplace design (external factors), poor adherence to communication standards and lack of memory cues (risk factors) are significant predictors of safety events. With respect to human error, lapses were found to predict two components of information processing; detection and auditory errors. Poor workplace design was found to be a significant predictor of lapses. The causal errors found to be significant predictors of safety events. These findings are summarized in Table 27, with the text in blue demonstrating the findings from step two; the core factors in relation to human error.

Table 27. Summary of the findings.

Step 1: Safety events			**Step 2: Human error**		
Predicted variable	**Predictor**	**Predictor type**	**Predicted variable**	**Predictor**	**Predictor type**
RI	Time since start	Shift variable			
	• Interpretation errors • Auditory detection errors	Information processing	• Interpretation errors • Auditory detection errors	Lapse	Human error
	Lack of memory cues	Risk factor			
LoS	Time since start	Shift variable			
	• Interpretation errors • Auditory detection errors	Information processing	• Interpretation errors • Auditory detection errors	Lapses	Human error
	Poor workplace design	External factors			
	Poor coordination standards	Risk factor			
	• Incomplete clearance issues • Radar and visual monitoring	Stated Causal factors	• Incomplete clearance issues • Radar and visual monitoring	• Knowledge based mistake • Slips	Human error
	Lapses	Human error	Lapses	Poor physical workplace design	External Factors

CHAPTER 5: DISCUSSION

The majority of the research in this field has been conducted in simulators (Eurocontrol, 2002, Zhang, Kaber, & Hsiang, 2009), focused on individual aspects of ATC and human error (Moon, Yoo, & Choi, 2011; Shorrock, 2005, Shorrock & Isaac, 2010) and aimed at developing a tool that identifies human error (Shorrock & Kirwan, 2002; Eurocontrol, 2004). As discussed in the theoretical background, there are a number of cognitive tasks and human factors that controllers bring to ATC, which are influenced by external factors, processing factors and a number of differrent elements. This research set out to identify the key aspects at the root of safety events and errors in ATC. It considered a number of variables that were deemed pertinent to processes in ATC. These included demographics, shift and event variables, human factors, external factors and risk factors.

This discussion will evaluate the results under each research question in order to gain insight into the various factors underlying errors in ATC. Firstly, the shift, event and demographic variables are evaluated. This is followed by a discussion of the findings with respect to safety events followed by an evaluation of the findings with respect to human error. Finally, all of the conclusions and findings are consolidated and brought together to demonstrate their applicability to the bigger picture.

5.1. Shift, event and demographic variables.

The first research question asked whether there are particular times in shifts when safety events are likely to occur. The most common occurring reported time since start of a shift was 30 minutes, 123 minutes and 319 minutes into the shift. The most frequent time since the last break was 20 minutes and the most frequent occurring time since position takeover was 32 minutes. These frequencies do not allow for viable conclusions regarding times in controller shifts when events are most likely to occur.

When grouped into shift times, results showed that 59% of the safety events occurred in the first shift (8:00 – 15:00 UTC). This shows that the first shift which occurs from 6:00 – 13:00 in South African time is the shift in which most safety events occur. When the data is grouped into time periods of an hour, the most frequent occurring time is 12:01 – 13:00 UTC, showing that the most common time in which safety events occur is between 10:01 and 11:00 in South African time. This time period falls within the last hour of the first shift.

When the time since start of shift data was grouped into time periods of 30 minutes, the most frequent occurring times of safety events are within the first 30 minutes of a controller's shift, followed by minutes 91 to 120 and minutes 121 to 150. Of the 92 controllers involved in safety events, 18.48% of the controllers were involved in an event within the first 30 minutes of a shift, 11.96% within minutes 91 to 120 and 11.96% within minutes 121 to 150. This shows that there are times within a shift that can be deemed 'at risk' times in which controllers are most likely to be involved in a safety event. These 'at risk' times are within the first 30 minutes of a shift and within the 91st to 150th minutes. Integrating this with the findings regarding shift times, 'at risk' times are within the first 30 minutes of a shift, between the 91st and 150th minutes as well as within the last hour of the first shift.

These are interesting time frames that present as the most hazardous times in which safety events are likely to occur. It may be posited that this is due to a vigilance decrement. The vigilance decrement is a decrease in performance over time resulting in decreases in efficiencies through slower detection times (Lanzetta, Dember, Warm, & Berch, 1987). According to vigilance theory, one would expect higher rates of safety events as the shift continues. However, this is not the case with ATC and safety events in South Africa. It seems that performance improves (i.e., the number of reported safety events decrease) after the first 30 minutes. It may be possible that the process of gaining an understanding of the situation when starting a shift uses a large quantity of attention resource, ultimately depleting them. This may lead to a vigilance decrement. Thereafter, once attention resources have been replenished, there is an increase in performance until later in the shift where an additional vigilance decrement may occur due to fatigue.

An alternative (but not contradictory) explanation is that safety events are likely to occur near the beginning of the shift while the controller builds up SA. Controllers who do not have a complete awareness of the situation may incur more safety events resulting in the higher risk of safety events in the first 30 minutes. Presumably the orientation and build up of SA would also deplete attention resources, leading to a vigilance decrement. The higher risk of safety events later in the shift could be due to a vigilance decrement caused by fatigue and/or the controller beginning to disengage from the task in preparation for whatever activities he/she will perform after the shift.

The regression analysis showed that time since start was a significant predictor of both LoS and RI. These findings suggest that there are particular times in a shift in which controllers are most likely at risk of being involved in a safety event; namely, within the first 30 minutes of a controller's shift and between the 91st and 150th minutes of a controllers shift. These frequencies support the claim made by ANSP that safety events occur within the first 30 minutes of a shift, but show that this is not the only at risk time of a controller's shift. Sawin and Scerbo (1995) posit that a decrease in performance most commonly occurs after the first 20 to 35 minutes. ANSP posited that most safety events occur within the first 20 to 35 minutes of a shift. This claim is supported by the evaluation of the data frequencies. The events may be occuring within the first 30 minutes of a shift due to vigilance decrement. The analysis of frequencies alone cannot establish vigilince decrement but rather posit it as a possible reason for this occurence. Again, one would expect higher rates of safety events occuring throughout the shift. This is not the case. Instead, the performance improves after the forst thirty minutes and decreases again over the 91st to 150th minutes.

When grouping time since position take over into time frames of 30 minutes, the first 30 minutes of a position takeover is the most frequent occurring time ($f=23$), followed by minutes 31 to 60 minutes ($f=10$). Again, this supports ANSP's claim that events occur within the first 30 minutes of a position takeover. Although this supports ANSP's claims, time since position takeover was not found to be a significant predictor of safety events. This was the case for all shift variables apart from time since start of shift. Following this, time since position takeover, time since last break, duration of last break, last 30 minutes of a shift, time since last sign off and days since last off day are not significant predictors of safety events. This implies that time since start of a shift is the only significant variable when considering the time frame of a controller's shift in which safety events are most likely to occur. Joining this finding with the time of day broken into shifts, the most at risk times are in the first shift (8:00 – 15:00 UTC), within the first thirty minutes of any shift and within minutes 91 – 150 of any shift.

Time since the start of a shift was the only significant predictor of events and is represented graphically in figure 16. It is noted that the arrow shows the direction of prediction and not causality.

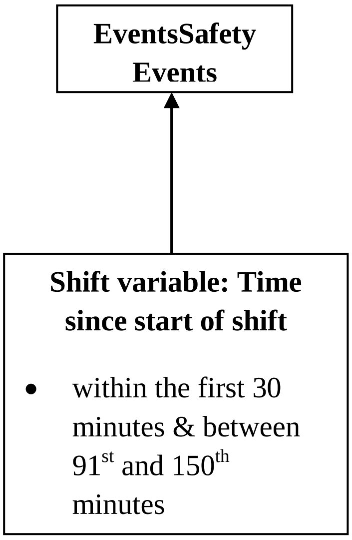


Figure 16. A graphic representation of the relationship between shift variables and safety events.

The second research question asked which event variables and demographic variables are common between events. Of the 93 controllers investigated, 77.4% were male and 22.6% were female. The most common occurring English proficiency was level 6 with only one controller reported at level 4. The most common occurring airport in South Africa at which the events occurred was International Airport X with the next highest at International Airport Y. International Airport X clocked 200 000 aircraft movements in the 2012/2013 financial year whilst all other regional airports together clocked around 190 000 (Airports Company South Africa, 2014). International Airport X is the busiest airport in South Africa and so it is expected that more events would occur there as there are more aircraft moving through the airspace. Statistically, an airport dealing with more aircraft volumes would incur more safety events than an airport with smaller aircraft volumes.

The range of movements through the different airports highlights the differing workloads undertaken by controllers at different airports. Workload is a function of the task demands placed on an operator as well as the capacity of the operator to meet those demands (Hopkin, 1995 as cited in Loft, Sanderson, Neal, & Mooij, 2007). The higher the demands, the more capacity is needed by controllers to meet those demands. Airports with more aircraft movements place higher demands on controllers and ultimately place more demands on controllers. Recall that increases in air traffic density and complexity substantially increase the demands on controller's mental workload (Wickens et al., 1997). Furthermore, workload is influenced by traffic volume and complexity (Moon et al., 2011) and high workloads can lower performance (Wickens et al., 1997). Increases in workload caused by higher traffic volumes and traffic complexity decrease performance and ultimately increase the probability of the occurrence of errors. The traffic volumes for airports considered in this research differ significantly and these traffic volumes ultimately affect the workload experienced by controllers.

The most commonly occurring sector for safety events occurred when aerodrome and approach sectors were combined, followed by approach, and finally radar west and east combined. It is important to note here that two of the three sectors reported with the highest levels of safety events are combined sectors. Recall that SACAA sets a maximum capacity at 30 movements per hour, but 22 of the 44 reported movements per hour (50%) that involved safety events were above 30 movements per hour. Cross tabulation showed that 36% of the occurrences of more than 30 movements per hour occurred in combined sectors. As stated before, sector combinations are based on expected traffic volumes. Occasionally the volumes are underestimated and sectors are combined when traffic loading exceeds maximum capacities. It has been suggested by investigating officers that the quality of ATC services deteriorate when traffic loading increases above quiet. This is not to say that the quality of the service is below adequate, but rather that the quality of the service is diminished somewhat when the quantity of traffic loading increases. This would suggest that an increase in traffic load results in a lower quality of ATC service. This could be linked to an increase in workload which can lead to a decrease in performance. In this case, the performance concerns the quality of ATC services. The evidence from the analyses would lend support to this claim as half of the reported movements per hour when safety events were above the maximum capacity and two of the three sectors reported with the highest levels of safety events were combined sectors.

5.2. Safety events

The first part of the next research question (research question 3) asked which human factors are associated with safety events. The results of the cluster analysis showed that mental models were associated with safety events but the logistic regression revealed that erroneous mental models are not significant predictors of safety events. Logistic regression showed that information processing was the only significant human factor that predicted safety events. Mental models are the mechanisms whereby humans are able to generate descriptions of the purpose of systems, explanations of system functioning as well as both observed system states and predictions about future system states (Rouse & Morris, 1986, as cited by Zang, Kaber & Hsiang, 2009, p.2).The result that mental models are not significant predictors of safety events is an interesting one as literature alludes to mental models as existing at the core of ATC. Here we see some overlap between concepts as parts of mental models can be seen as coinciding with information processing. Mental models require the observation of system states as well as predictions about future system states. The observation of system states show commonalities with the perceptual encoding of information processing. Mental models may have been found non-significant as errors in ATC in South Africa occur in the information processing stages which filter in and inform the mental model.

The information processing cluster included the quality of information received by the controller, controller interpretation of the information as well as errors in the detection of visual and auditory cues. Linking these factors back to the information processing model (figure 5), it can be seen that the information received by the controller is categorised under sensory register which lies in the encoding stage of information processing. Errors in the detection of auditory and visual cues refer to the actual perceptual encoding and ‘perception’ stage of information processing. Controller interpretation of information falls under the central processing stage. Logistic regression showed that interpretation errors and auditory detection errors are strong predictors of both RI and LoS. Following the model of information processing established in the literature review and the results it can be seen that errors in the perceptual encoding stages (errors in auditory detection) and central processing stages (errors in interpretation) are of the most significance to controllers in South Africa.

Errors in the detection of auditory cues show that safety events are predicted by errors in the perceptual encoding of information. Perceptual encoding is the “process by which the five senses translate environmental stimulation into mental representation” (von Hippel, Jonides, Hilton, & Narayam, 1993, p. 921). Recall that controllers rely on both radar displays, visual views of runways and radio telephony, showing that the environmental stimuli that controllers have to encode are both visual and auditory. From the results, it can be seen that safety events are predicted by a breakdown in the process by which controllers translate auditory environment stimuli into mental representation. Auditory environment stimuli include verbal radio interactions between controllers, controllers and pilots as well as warning signals from the STCA. Controllers may be displaying a breakdown in encoding communications with other controllers or pilots or in their response to STCA alerts. There have been a number of complaints regarding false STCA alarms going off. If the STCA system has given a number of false alerts, controllers may not treat alerts from the STCA with as much attention as they should as they may be primed to think it is another false alert.

A definitive conclusion cannot be drawn regarding the phase of perceptual encoding in which the errors are occurring. However, since controllers are medically cleared, it can be assumed that controllers are medically fit and their hearing is of a standard deemed fit for operation. This would imply that the auditory detection errors are occurring at the 'perception' stage during which meaning is added to information received. This is done by comparing it to permanent information brought forward by long term memory (Wickens, Gordon, & Liu, 1998).

Recall that schemata play a vital role in information processing in that they shape what we see and hear as well as how we store information and access that information at a later stage (von Hippel, Jonides, Hilton, & Narayam, 1993). Schematic processing could possibly inhibit perceptual encoding in that schema guide interpretation and selective attention. Individuals lacking adequate schema must rely on an effortful integration of information (von Hippel, Jonides, Hilton, & Narayam, 1993). Attentional resources direct perception (figure 5), which directs and informs response execution plans. If controllers are displaying errors in the perceptual stage of information processing, this may be due to a number of issues related to perceptual encoding. If attentional resources direct perception and the controllers are showing errors in perception, then the error may be traced back to the allocation of attention resources. Controller schemata may inhibit the allocation of attention resources, resulting in the controller missing crucial information.

The regression analysis showed that controllers displaying errors in auditory detection are 33.5 times more likely to be involved in a LoS than a controller displaying adequate auditory detection and 46 times more likely to incur a RI. The confidence interval showed that these controllers are at least 2.63 times more likely and at most 409 times more likely to cause a LoS and at least 5.17 times more likely to incur a RI. These substantially large confidence intervals indicate a highly possible overestimation related to the small number of observations for auditory detection as an explanatory variable (Nemes, Jonasson, Genell & Steineck, 2009). This indicates that caution should be exercised when interpreting the odds ratios and although a predictor, it cannot be confidently concluded thaterrors in auditory detection in controllers are a significant predictorof safety events. Although caution must be exercised, future studies and interventions may focus on the impact of errors in auditory detection on ATCO performance.

Error in the interpretation of information occurs in the central processing stage and shows that safety events are also predicted by a breakdown in the central processing of controllers. The central processing stage involves decision making processes (figure 5). From an information processing perspective, decision making represents a mapping of copious information received to one or few responses (Wickens & Hollands, 2000). It can be posited that an error in perceptual encoding may lead to an error in decision making. When there is an error or inadequacy in the information received this may lead to the mapping of inadequate information. According to the information processing approach to decision making, selective attention, working memory and long term memory are critical components of decision making. It has already been shown that errors in selective attention may lead to the incorrect allocation of resources, and by extension to inadequate perceptual encoding. Decision making involves cue reception and integration, hypothesis generation, hypothesis evaluation and selection, and the selection and generation of actions (Wickens & Hollands, 2000). An error in the cue reception and integration impacts hypothesis generation, evaluation and selection. The errors in central processing stage may stem from errors in the perceptual encoding stage. This conjecture is supported by the evaluation of the cognitive limitations that limit decision making. These include the amount or quality of the information cue, the attentional resources allocated to the activity, the amount or quality of the individual's knowledge of the situation, an individual's ability to retrieve relevant information or hypotheses and lastly an individual's working memory capacities (Reason, 1990).

Recall that schemata play a vital role in information processing in that they shape what we see and hear as well as how we store and acces information (von Hippel et al., 1993). A perceiver relies on prior conceptualizations in order to understand specific instances and current circumstances. This facilitates the interpretation of incoming information. If, as previously mentioned, certain stimuli such as the STCA alerts have falsely gone off, a controller may be inclined not intepret incoming information based in prior conceptualisations of false alerts. The false alerts may facilitate inadequate schema. If the schema is inadequate, the controller may devote attentional resources to relevant information while ignoring information the controller deems irrelevant (such as STCA alerts) which in actual fact may be relevant.

The supposition that erroneous central processing is initiated at the perceptual encoding stage is supported by the decision making and SA model (figure 7). The model shows that from goal to action, a controller must perceive, understand and think ahead. Errors in perceiving and understanding will impact the way in which controllers think ahead, distorting the path from goal to action. The regression showed that auditory and visual interpretation errors in controllers are 46 times more likely to incur a RI than correct interpretation processes and 6.53 times more likely to incur a LoS. The confidence intervals and odds ratios show that controller interpretation errors are a stronger predictor of RI than LoS but may indicate overestimation in the logistic regression. . Although it's impact may potentially be overestimated, future studies mayexamine the role of interpretation errors and decision making in the human errors in ATC in South Africa.

It can be said that although most of the human factors variables were regarded as insignificant predictors of safety events in the logistic regressions, some of them essentially filter into the information processing model. Information processing encapsulates memory, attention resources, perception and sensory registration. In terms of information processing, it can be concluded that errors occur at the perceptual encoding and central processing stages. These stages utilize cognitive processes such as memory, attention and decision making. It can thus be said that these human factors are, by extension, related to safety events caused by controllers. This finding can be added to the findings for shift variables and represented graphically in figure 17, with the arrows denoting the direction of prediction.

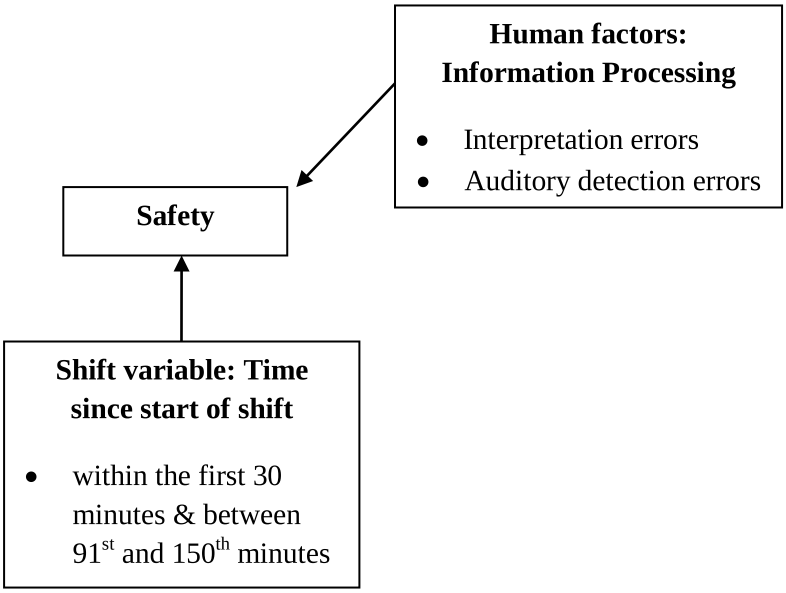


Figure 17. A graphic representation of the findings thus far.

The next part investigated which external factors are related to safety events. Cluster analysis clustered poor workplace design with combined sectors and RI, but not with LoS. Logistic regression showed that poor workplace design was a significant predictor of both LoS and RI whilst the direction of the regressions suggested that airports with poor organisational design are 7.8 times more likely to incur a LoS. The odds ratio shows that poor workplace designs are 9.95 times more likely to incur RI than adequate workplace designs.

Poor workplace design incorporated the physical design of the workplace as well as the staffing design. Logistic regression showed that poor physical workplace design is a predictor of both LoS and RI whilst the staffing design was not a significant predictor of either. The analysis showed that poor physical workplace designs are 7.27 times more likely to incur a LoS than adequate physical setups, and 7.2 times more likely to incur a RI. Both predictions (for LoS and RI) showed significant confidence intervals, suggesting that poor physical workplace design is a strong predictor of safety events.

The physical setup and design of the workplace and controlling area is a predictor of RI and LoS events. This is intuitively sound as many of the poor designs hinder procedures such as runway visual scans, which are essential in preventing runway incursions. Controllers who are hindered to some degree by the workplace design may execute improper scanning and visual procedures, resulting in runway incursions. ATC terminal staff depend on radar was well as a visual view of the runways in order to issue control instructions that provide adequate separations. Workplace designs that hinder visual monitoring of the runways may result in inaccurate control instructions that provide less than adequate separations.

The ergonomics of the control facilities and workplace set up can be noted as a significant predictor of safety events and can direct future research. Anthropometrics is a factor of ergonomics and is concerned with the matching of the physical demands of the working task to the workplace (among others) (Pheasant & Haslegrave, 2006). The anthropometrics of the workstations at which the controllers are expected to perform physical tasks such as runway scans and visual monitoring should be explored in order to maximise the ease with which controllers can perform the physical tasks required of them.

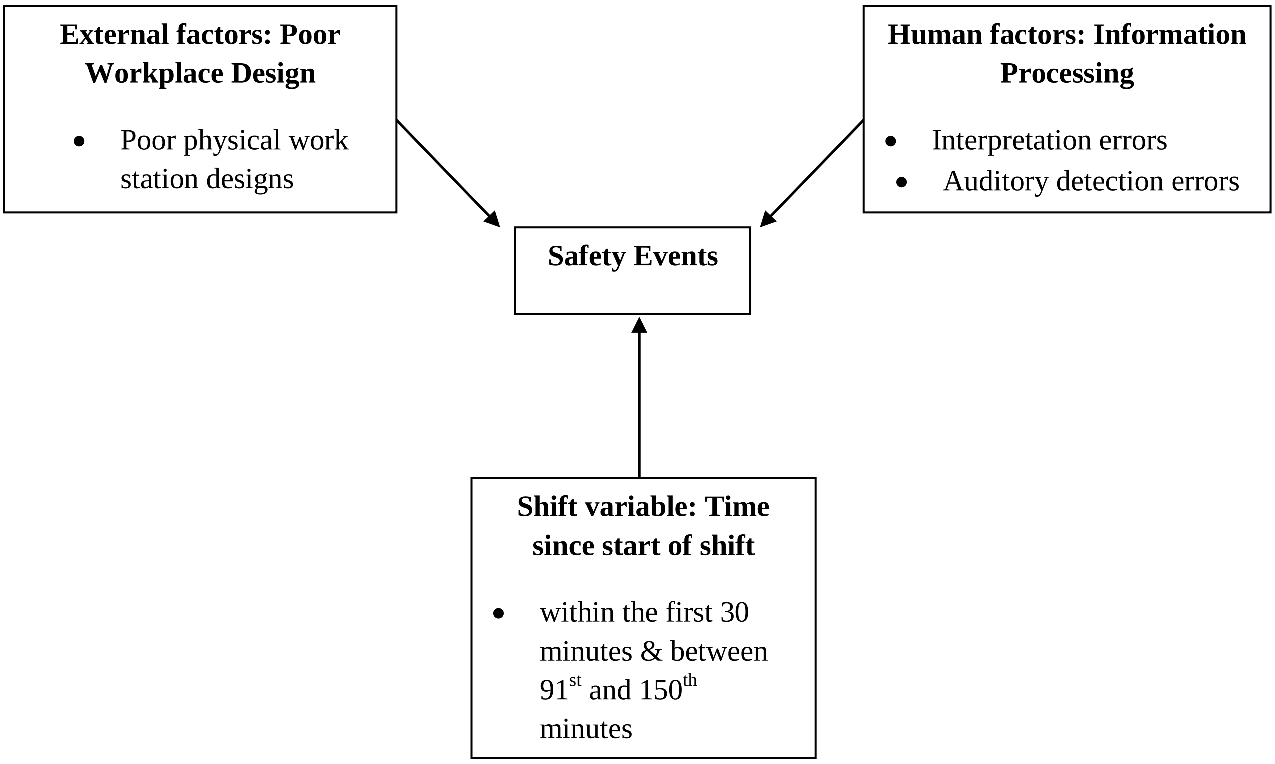


Figure 18. A graphic representation of the relationship between shift variables, human factors and external factors with safety events.

The next part asked which risk factors are related to safety events. Recall that risk factors included failure to respond to alerts, unclear position takeover, poor co-ordination standards, pilot-controller communication, failure to pass essential traffic information to aircraft, poor R/T phraseology use and lack of memory cues in the environment. Logistic regression showed that poor adherence to co-ordination standards is a significant predictor of LoS while a lack of memory cues in the environment is a significant predictor of RI. Poor adherence to co-ordination standards between controllers is 16.26 times more likely to incur a LoS than adherence to co-ordination standards. It is noted that caution should be exercised when interpreting this result due to possible overestimation. Poor adherence to co-ordination standards between controllers only renders controllers .05 times more likely to incur a RI than adherence to coordination standards (showing weak prediction for LoS). This is logically sound as RIs occur on runways that are governed by one unit of controllers. RIs usually involve one controller allowing an aircraft or vehicle access to a runway that is already occupied. This does not entail coordination between controllers as only one controller is responsible for the runway at a time.

A LoS involves an infringement of both horizontal and vertical separation minima in controlled airspace (International Civil Aviation Organization, 2013) and by extension, can only occur when an aircraft is in the air. Recall that the three ATC facilities control different areas and heights, essentially splitting airspace between different ATC facilities. As aircraft pass through airspace they are handed over to the controllers responsible for that airspace. These facilities are in constant communication with each other as they hand aircraft over from one area to the next. This involves efficient coordination and communication between the control areas. It is logical that poor adherence to co-ordination standards effects LoS more significantly than RIs as LoSs occur in airspaces that are controlled by different ATC facilities.

Co-ordination is defined as the "organisation of the different elements of a complex body or activity so as to enable them to work together effectively" (Pearsall, 2005, p. 210). Following this, the controllers can be seen as the different elements of the complex system of ATC and without their organisation, they are unable to work effectively, resulting in safety events. Adherence to coordination standards must be investigated when looking to reduce incidences of LoS.

A lack of memory cues at the workstation refers to controller failure to update or move FPS to represent aircraft movements. The lack of memory cues at a station is 15.05 times more likely to incur a RI than at a station with memory cues. Memory cues serve to remind controllers of the various aircraft movements in their sector. Without the FPS to serve as a reminder, a controller is at least 2.3 times more likely to incur a RI and at most 98.62 times more likely. This is a significant confidence interval, once again demonstrating the possibility of overestimation due to the small number of observations of explanatory variables (Nemes, Jonasson, Genell & Steineck, 2009). Discretion must be used when interpreting the strengths of predition with respect to lack of memory cues. Controller work with FPS and FPB should be of a standard by which strips are moved to correspond to all movements in the controller's sector. These findings can be viewed in conjunction with the previous findings to see the progress thus far (figure 19).

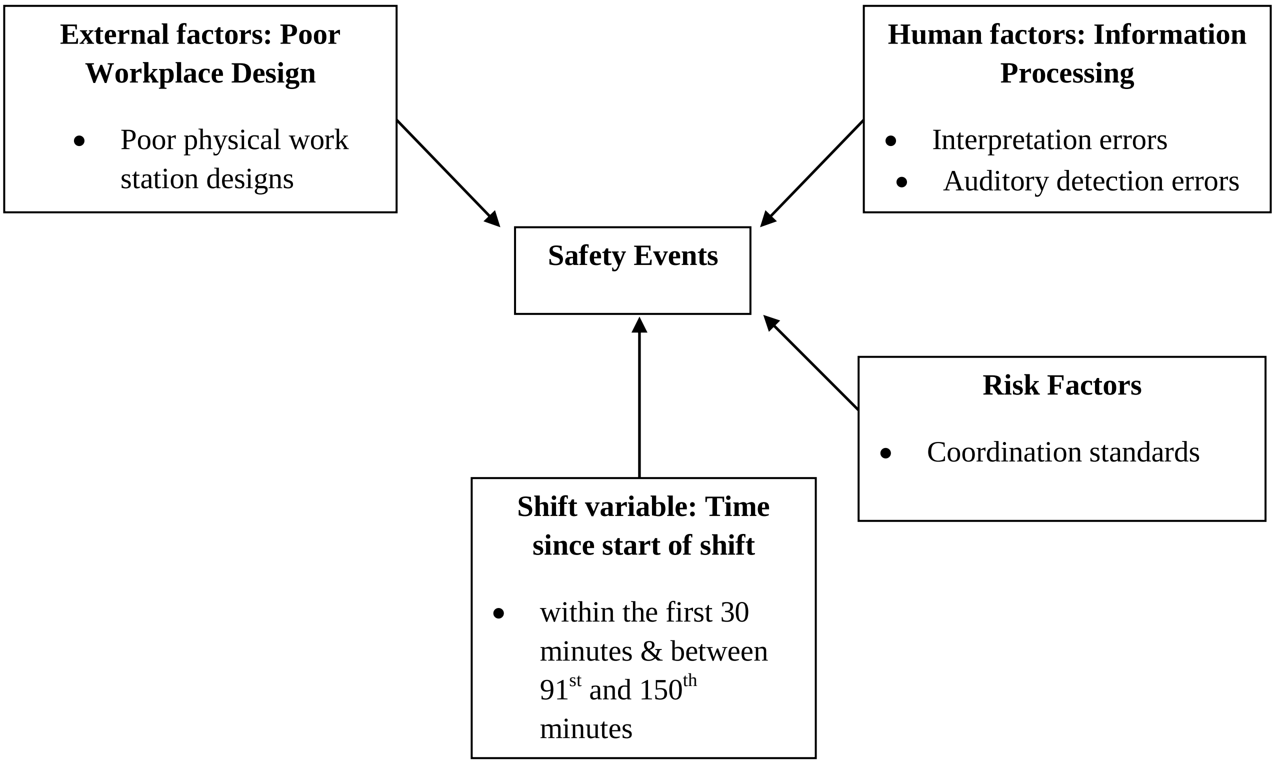


Figure 19. A graphic representation of the results.

The last facet of research question 3 concerned stated causal factors and their prediction of safety events. Causal errors included memory lapse, mishear of read-back, incomplete clearances issued, incorrect timing in issuing of clearances, misjudging aircraft, radar and visual monitoring failure, incorrect assumptions regarding separation, and instructions issued to the wrong aircraft. These were the reported or stated causal errors in the safety event investigation reports.

Logistic regression showed that at least one causal error is a significant predictor of LoS and analysis of the variables in the equation showed that four factors are significant predictors of LoS; incomplete clearances issued, misjudging aircraft, radar and visual monitoring failures and incorrect assumptions regarding separation (Table 18). Misjudged aircraft projections and incorrect assumptions regarding separation were weak predictors of LoS, leaving the outcome of only two causal errors as strong, significant predictors of LoS, namely; incomplete clearance issues, and radar and visual monitoring failures. Controllers issuing incomplete clearances are 13.86 times more likely to incur a LoS and controllers who make incorrect assumptions regarding separation are 10.59 times more likely to incur a LoS.

Logistic regression showed that only two causal factors predicted RI; incomplete clearance issues, and radar and visual monitoring failures. The odds ratios and confidence intervals showed that neither incomplete clearance issues nor radar and visual monitoring failures are strong predictors of RI. It is interesting to note that the two events have differing causal error predictors.

When linking causal errors back to the human errors model (figure 3), it can be seen that a LoS is predicted by errors in issuing incomplete clearances (in controller plan and action intention) and radar and visual monitoring failures (situation assessment). Monitoring situations can be linked back to the interpretation or assessment of situations, which, according to Reason's representation of human error (figure 3 on page 17) correlate with knowledge-based mistakes. This shows that causal errors that predict LoS for controllers in South Africa lie within their assessment and interpretation of the situation, which in turn is indicative of knowledge-based mistakes. Incomplete clearance issues are based in erroneous and inadequate plans which link back to lapses. This is explored further when the links between causal errors and human errors are established.

Incomplete clearance issues and radar and visual monitoring failures can also be discussed in terms of which stage of information processing they occur. Radar and visual monitoring failures are rooted in the perceptual encoding stages of information processing and incomplete clearance issues are rooted in the response stage of information processing. Recall that the perceptual encoding stage entails the translation of environmental stimuli into mental representation through the use of the five senses. The sense that is incurring the error in radar and visual monitoring failures is sight. Controllers may be displaying problems in the encoding of visual information. As per the model of human information processing, perception informs response selection. It is thus logical that an error in perception would feed into response selection, resulting in erroneous response selections based on erroneous perception. If this is the case, addressing issues at the perception stage may filter through and address issues in the response stage.

An alternative explanation can be found in theories of attention. The errors in radar and visual monitoring could possibly be caused by failures in concentration and the deployment of attention. Recall that vigilance tasks impose substantial demands on the information processing resources of the observer (Warm et al., 2008). As previously discussed, it can be seen that the significant causal factors can be rooted in the stages of information processing.

In particular, these stated causal errors correlate with errors in the perceptual encoding and response stages. Controlling is a vigilance task and following the research, the workload placed on operators performaing vigilance intensive tasks drain information processing resources, leading to lowered vigilance states (Warm et al., 2008). The errors in visual and radar monitoring and clearance issues may be due to a lowered state of vigilance. The vigilance intensive task and the resulting workload may be draining information processing resources, resulting in errors in the perceptual encoding and response stages.

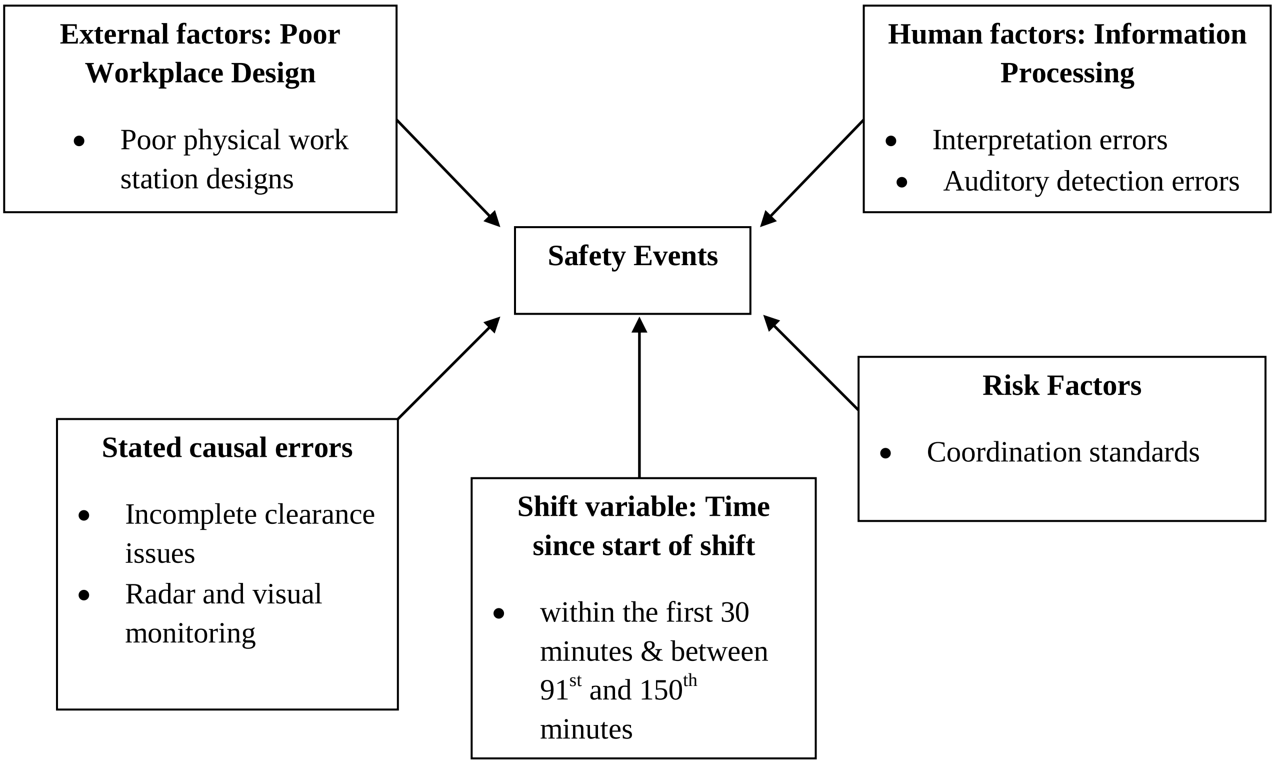


Figure 20. A graphic representation of the relationship between the covariates and safety events thus far.

5.3. Human error

The scheme adopted by this research (figure 3) is led by the supposition that a human operator is met by stimuli from the environment, and has the potential to interpret the information correctly or incorrectly. Given that interpretation, the controller may or may not have the intention to carry out the right action in response to the stimuli and finally may or may not execute the intended action correctly (Wickens & Hollands, 2000). Following this, there are three primary phases in which error may occur. Human errors are categorised into three distinct kind of errors that occur at the different phases; slips, lapses and mistakes (both knowledge and rule based).

The first part of research question four asked which errors human factors are related to. No evidence was found to support the cluster analysis results which suggested that knowledge based mistakes, attention and decision making were related, or that rule based mistakes, lapses and human-machine interface were related (refer to Figure 13, p.70). When the components of information processing were entered into a logistic regression with the four human errors (knowledge and rule based mistakes, slips and lapses) it was found that lapses were significant predictors for both interpretation errors and auditory detection errors, with controllers who experience lapses 7.52 times more likely to incur an incorrect interpretation and 8.14 times more likely to miss auditory cues than not. It is interesting to note that the only information processing factors that yielded significant predictors were the two factors that were themselves significant predictors of safety events. Alternatively stated; the analysis showed that lapses are a significant predictor of interpretation errors and auditory detection errors and that interpretation errors and auditory detection errors are significant predictors of safety events.

Lapses are defined as "errors which result from some failure in the execution and or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective" (Salmon, et al., 2011, p. 9). Since lapses occur in the execution and or storage of an action (i.e. within the action stage) it is evident that human factor errors (information processing errors) in ATC in South Africa are rooted in intention formation and planning (figure 3).

As posited earlier, errors in auditory detection and interpretation may be linked to errors in perceptual encoding (figure 5). Auditory detection errors link to perceptual encoding errors which lead to central processing errors. The central processing stage involves the formulation of responses and decision making. This can be equated to intention formation and planning. Here we see that the errors in information processing correspond with the human errors at the root of those errors. Lapses can be brought in to the graphic representation to show how it fits in to the bigger picture (figure 21)

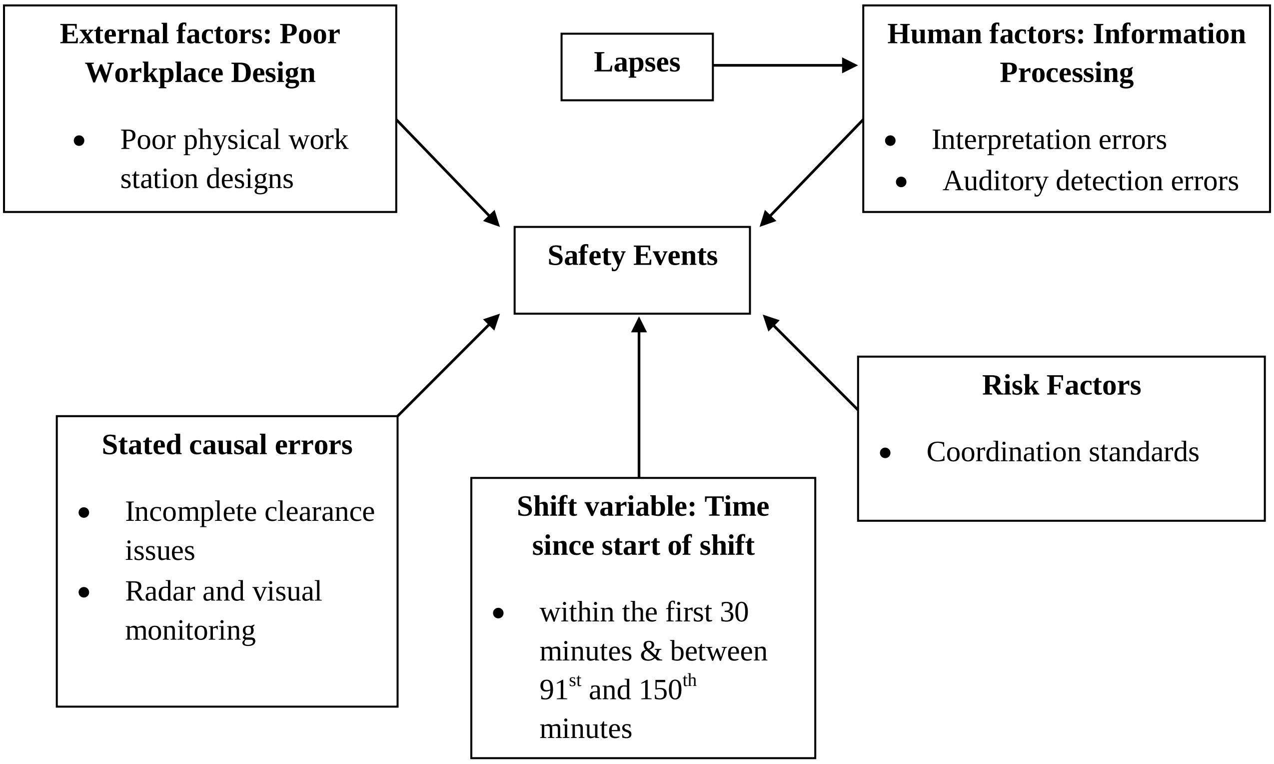


Figure 21. A graphic representation incorporating the relationships found thus far.

The next question regarded which errors are related to external factors. Analyses showed that workplace design was a significant predictor of lapses in controllers involved in safety events. No other external factors predicted any human errors. The results showed that controllers in poor workplace design are 12.34 times more likely to experience a lapse than controllers in adequate workplace design. This a substantial increase in lapses. Although the direction of prediction has changed, lapses are once again the primary human error that showed any significant results. Lapses are errors which result from some failure in the execution and or storage of an action sequence (Salmon, et al., 2011). Lapses may possibly be related to the inability of controllers to perform adequate visual scans of runways due to poor physical workplace designs.

The components of workplace design were entered into logistic regression and it was found, once again, that physical workplace design was the only significant predictor of lapses in controllers. Lapses are errors which result from failure in the execution and or storage of an action sequence (Salmon, et al., 2011, p. 9). The physical workplace design considered the anthropometric dimension of ergonomics, namely; the physical setting of the workplace and workstation and how this hindered or aided controller tasks. The analysis showed that the physical set up of a work station is a predictor of lapses in controllers in South Africa. This infers that poor physical designs of work stations predict errors due to a failure in the execution and or storage of an action sequence. This is a coherent finding in that poor workspace designs hinder the execution of action sequences such as visual scans of runways. It is both plausible and reasonable that poor workplace design predict lapses in controllers.

It could alternatively be posited that poor workplace designs require more attentional resources to be deployed and as a result, controllers may experience greater resource depletion. Vigilance was defined as, “a capacity for sustained effective attention when monitoring a situation or display for critical signals, conditions or events to which the observer must respond” (Donald, 2008, p. 36). If the ability of a controller to monitor a situation or display for critical signals or conditions is hindered by poor workplace design, the controller cannot achieve sustained effective attention. It it is logical then that poor workplace designs (and the resulting hinderance to monitoring abilities) predict lapses which are errors which result from some failure in the execution of an action.

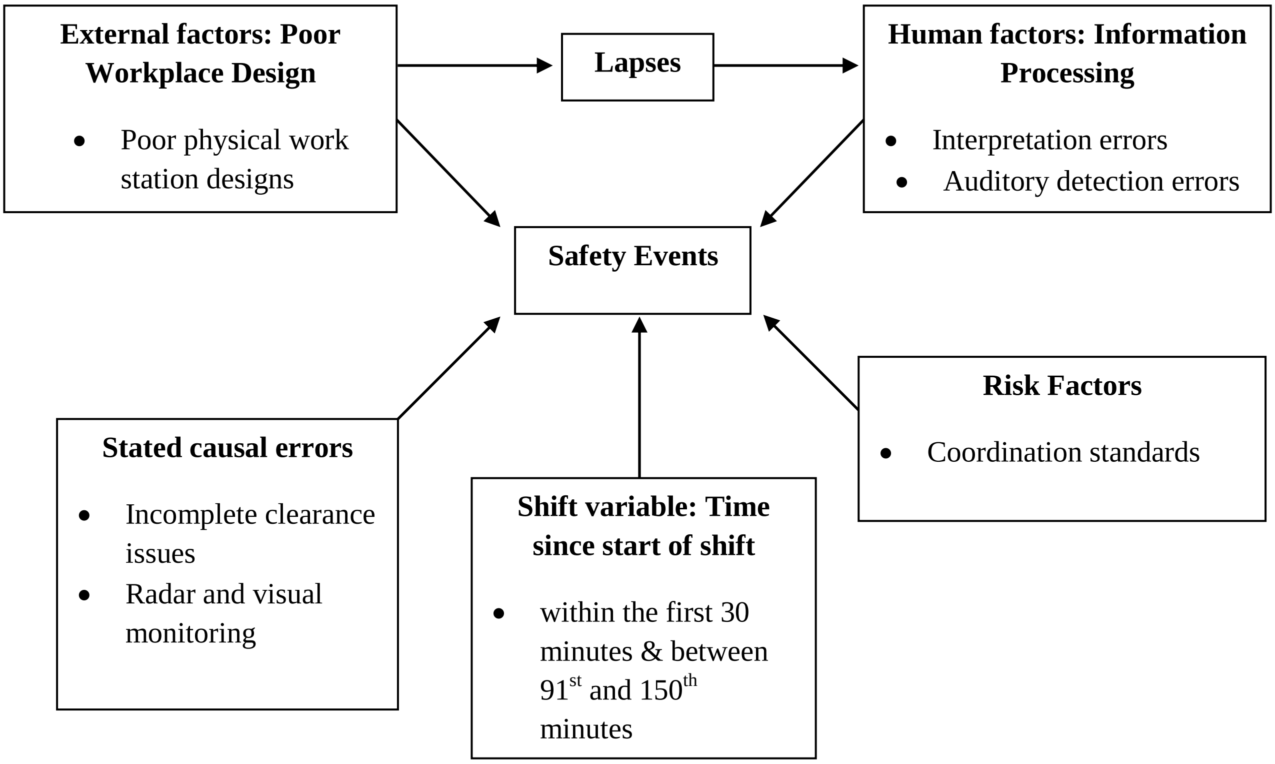


Figure 22. A graphic representation of the relationships found.

The next part of the research question asked if stated causal errors related to certain human errors. Logistic regression showed that incomplete clearances, radar and visual monitoring failures, incorrect assumptions regarding separation and misjudging aircraft projections were predictors of LoS, whilst incomplete clearances and radar and visual monitoring failures are predictors of RI. As these are the predictors of safety events, the other causal factors and their human error predictors will not be discussed as their relationship to safety events are not significant.

Logistic regression revealed that rule based mistakes are predictors of incorrect assumptions, slips are shown to predict radar and visual monitoring failures, misjudging aircraft projection, incorrect timing of clearances and memory lapses and knowledge based mistakes were shown to predict incomplete clearance issues and mishearing of read-back. As only incomplete clearance issues and radar and visual monitoring errors were significant predictors, only these two causal errors will be discussed.

Incomplete clearance issues are predicted by knowledge based mistakes while radar and visual monitoring failures are predicted by slips. Knowledge-based mistakes predicting errors in visual monitoring failures was expected as monitoring failures are indicative of errors in situation assessment. Recall that mistakes are “failures in judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision scheme run according to plan” (Salmon, et al., 2011, p. 9). Errors in radar and visual monitoring failures are logically rooted in knowledge based mistakes as knowledge based mistakes are linked to errors in interpretation of stimuli.

A slip predicting incomplete clearance issues is logically sound as slips correspond to errors in action execution. Slips are “errors which result from some failure in the execution and or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective” (Salmon, et al., 2011, p. 9). Here we see that the error lies in the execution of the action sequence. This contradicts the claim made earlier in the discussion in which it was posited that incorrect clearance issues are rooted in the formation of a plan, rather, it is rooted in the execution of the action. This may be because of the nature of information processing and the manner in which one stage feeds into the next. Errors in perception obscure response selection which results in erroneous response execution. It can be posited that the errors are all linked and influence each other, making errors in all three stages in information processing a likely find.

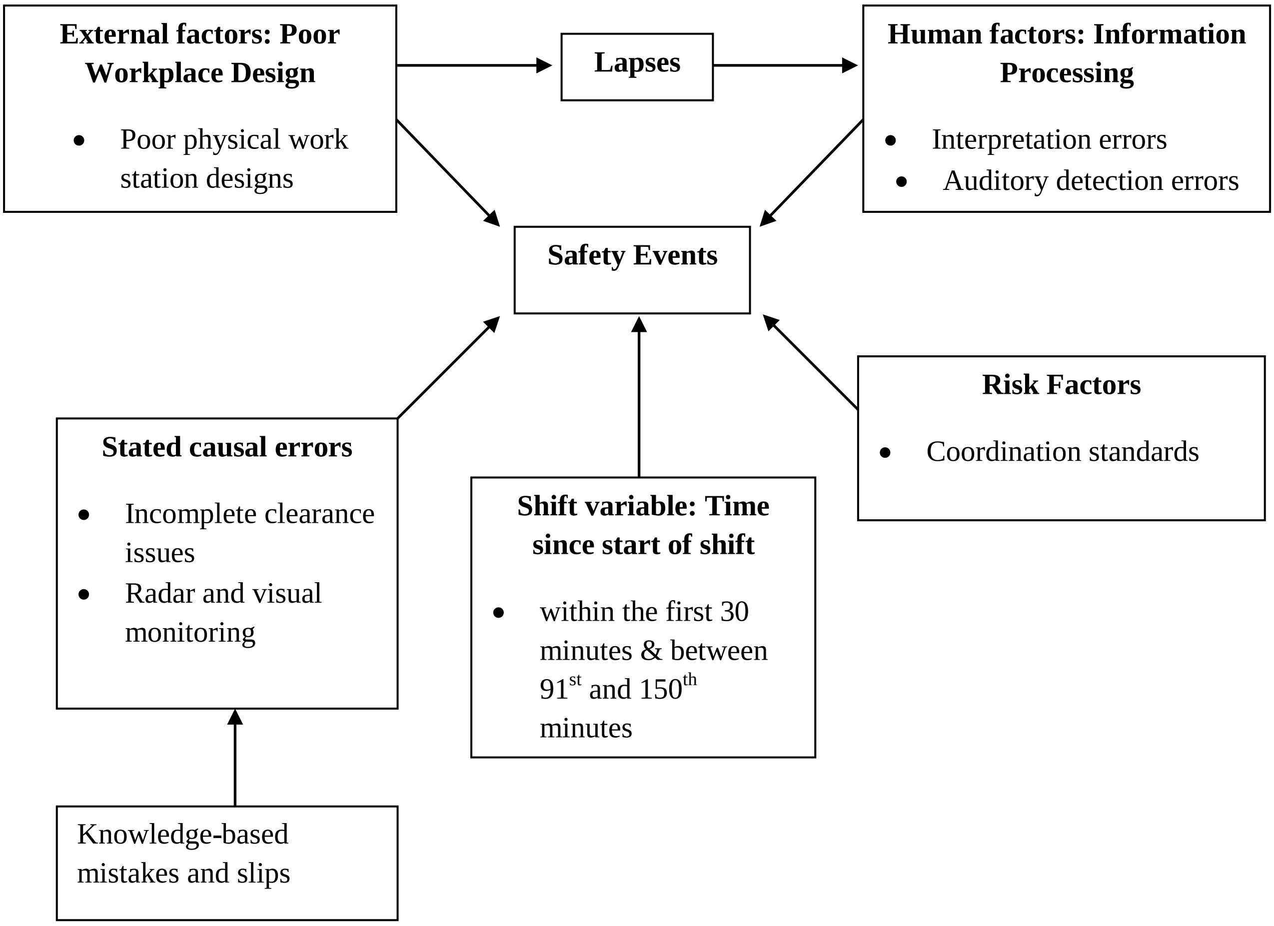


Figure 23. A graphic representation of the significant relationships found thus far in this study.

The next question regarded if safety events are related to certain types of human error. Lapses were established as a significant predictor of safety events. Recall that lapses occur in the planning stage, in which the intention to act is erroneous. This implies that safety events in South Africa can primarily be predicted by errors in planning phases. The planning phase in ATC involves the revision of current plans for controlling sectors to match contingencies, implementing ways of avoiding conflicts and changing aircraft routes in response to the situation (Seamster, Redding, Cannon, Ryder, & Purcell, 1993). All of this planning occurs in real time and thus present controllers with a challenging task with a restricted amount of time in which to formulate and consolidate sufficient plans. Errors that occur in the planning phase involve erroneous intention formulations, for example the formulation of inadequate conflict avoidance plans.

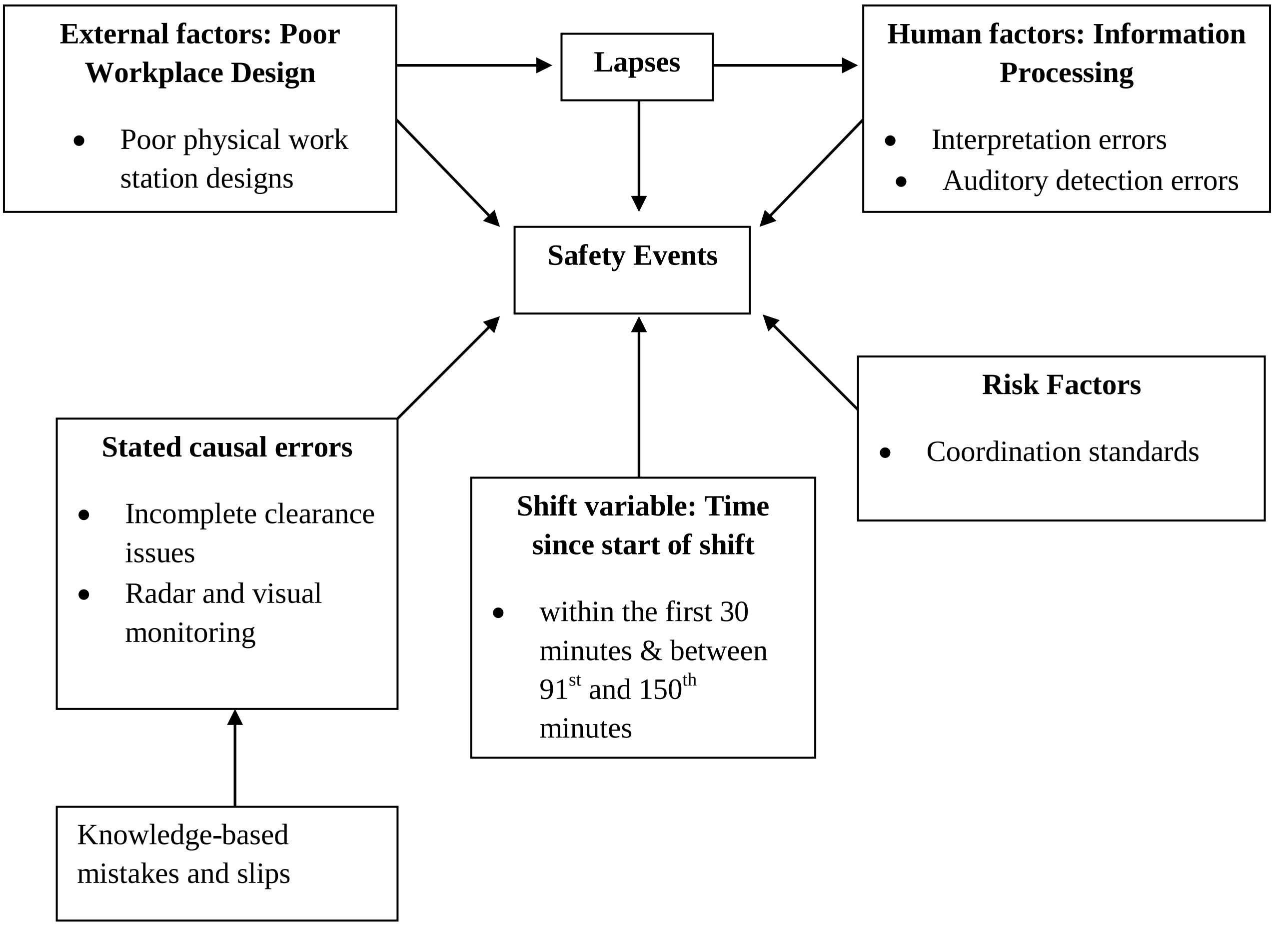


Figure 24. A graphic representation of all the significant relationships found in this study.

5.4. Summary of findings.

The results showed that errors in information processing factors, workplace design, poor co-ordination standards and lack of memory cues are predictors of safety events. It was then established that lapses are predictors of poor information processing in controllers whilst poor workplace design is a predictor of lapses. Finally, lapses are a predictor of safety events. A final graphic representation of the results was shown in figure 24. It was noted that the arrows show prediction and in no way suggest causality. The results presented an interesting possible relationship between poor workplace design, lapses and information processing errors. Not only did all three factors (poor workplace designs, lapses and information processing errors) individually predict safety events, there were two paths of note that developed. Firstly, poor workplace designs predicted lapses which in turn predicted safety events. Secondly, poor workplace designs predicted lapses which predicted errors in information processing which in turn predicted safety events. These paths show that there could possibly be some mediation at play. It is possible that lapses mediate the relationship between poor workplace designs and information processing errors.

A mediating variable is one caused by the predictor variable and in turn causes the outcome variable (Stangor, 2011). Mediating variables are important because they explain why the relationship between two variables occur (Stangor, 2011). It would be logically and theoretically sound to view lapses as the reason why (mediating variable) the relationship between poor workplace designs and errors in information processing occurs in controllers. Alternatively phrased, it is theoretically sound to posit that there is a relationship between poor workplace designs and errors in information processing because poor workplace designs encumber the execution of an action sequence. The obstruction of the execution of certain actions causes errors in information processing. This shows that the possibility of lapses as a mediating variable is both logically and theoretically sound.

CHAPTER 6: CONCLUSIONS

This study investigated the factors underlying human error in ATC by assessing safety event reports from years 2010 to 2012. This was achieved through content analysis, cluster analysis and a number of logistic regressions. The study found a number of significant predictors of both RI and LoS from the various covariates. Firstly, the research established that there are times in a shift which can be labelled as risk times. Time since the start of a shift is a predictor of safety events and the most at risk times are within the first thirty minutes of a shift and between the 90th and 150th minutes. The research found that errors in information processing are significant predictors of LoS and RI, in particular, errors in auditory detection and interpretation. The research can thus conclude that the human factor at the root of errors in ATC in South Africa is information processing. These errors in information processing are predicted by lapses. It can thus also conclude that the human error at the foundation of errors in information processing is lapses.

The research found that poor physical workplace designs are predictors of both RI and LoS. Poor physical workplace designs are also predictors of lapses in controllers. Of all the variables included in the study, this was the only external factor that predicted any human error. It can thus be concluded that poor workplace designs are the core problem when considering the impacts external factors have on controllers in South Africa. The possibility of other external factors that were not included in the reports that may not have considered under other variable headings such as distraction. This variable was coded into task engagement but could have been factored into an external variable when considering the amount of distraction from within the workplace. In this way, the study incorporated it into a human factor and thus ensured that it was still considered in the study. In terms of the variables included in the study, physical workplace design was the only significant external factor that predicted any human error. The research also notes that poor physical workplace designs predict both lapses and safety events. Lapses in turn predict errors in information processing as well as safety events and errors in information processing predict safety events.

The research concludes that poor adherence to coordination standards predict LoS events while a lack of memory cues predicts RI events. Incomplete clearance issues and radar and visual monitoring failures predict LoS events and in turn are predicted by knowledge based mistakes and slips. The final conclusions of this research can be stated as follows. There are a number of factors that interact and influence controller performance in ATC. When considering human factors, lapses are the primary human error at play. When considering the causal errors, slips and knowledge based mistakes are at the base of human errors in ATC.

6.1. Limitation and suggestions for future research

There were a number of limitations to this research, most originating from time constraints. Firstly, the sample size was relatively small and analysing years 2008 to 2012 would have allowed for a more in depth and conclusive evaluation of errors in ATC. If the sample size was bigger, the researcher may have found it useful to separate reports into major airports and run analyses on the airports. If the research had been conducted according to airports, future preventative measures may have been tailored to the airport and its specific needs. The amalgamation of airports may have resulted in the issues of smaller airports being lost due to the number of events occurring at larger airports. A larger sample size would also have allowed for more inclusive regressions as the number of observations would outweigh the number of model parameters. Secondly, the researcher was unable to incorporate inter-rater reliability due to time constraints. Inter-rater reliability would essentially have tested the data more than once, and ensured that the initial content analysis of the safety event reports was consistent.

As ATC is so complex, there are a number of extraneous variables that may not have been considered by the researcher. Future research may consider variables that were not considered in this research such as psycho-physiological aspects, for example; stress. Future research may use this research as a guide in developing interventions aimed at combating errors in ATC. It is recommended that the significant predictors be addressed in future studies and used as a basis from which to improve the training of controllers. Lastly, future research could explore the dynamic relationship between the physical design of controller workstations, lapses and information processing. With more data, future research may be able to establish some mediation roles in human errors, for example lapses mediating the relationship between physical workplace design and information processing errors.

Future research should look to take ATC research away from the diagnostics of errors and move towards a proactive approach that may lessen human error in ATC. Professor Sidney Dekker, from the Griffith University in Brisbane, Australia, delivered his paper, "I wish I could get rid of the people who make mistakes" at the human factors symposium in

Johannesburg. Professor Dekker suggests that systems are essentially safe if not for the few unreliable people within it (Air Traffic and Navigation Services, 2014) . He also posited that the focus on human error has the danger of becoming a focus on humans as the cause of safety events and on humans as the targets for intervention (Air Traffic and Navigation Services, 2014). This may serve to be a mislead safety endeavour, as getting rid of one person does not remove the conditions that gave rise to the safety event (Air Traffic and Navigation Services, 2014). This research has considered not only the human factors but the external and risk factors in order to establish a more comprehensive account of the factors that underpin errors in air traffic control. This may assist future research in directing focus away from human factors but allow them to consider other factors such as workplace designs and risk factors. In this way, the conditions that facilitated the errors can be addressed and bettered.

Although the results have indicated predictors of safety events in ATC, this research was limited in its estimations of the strength of the prediction. The small to moderate sample size caused possible biases in results. Despite the overestimation, predictors were identified and future studies may use these findings to direct the focus of future studies and interventions.

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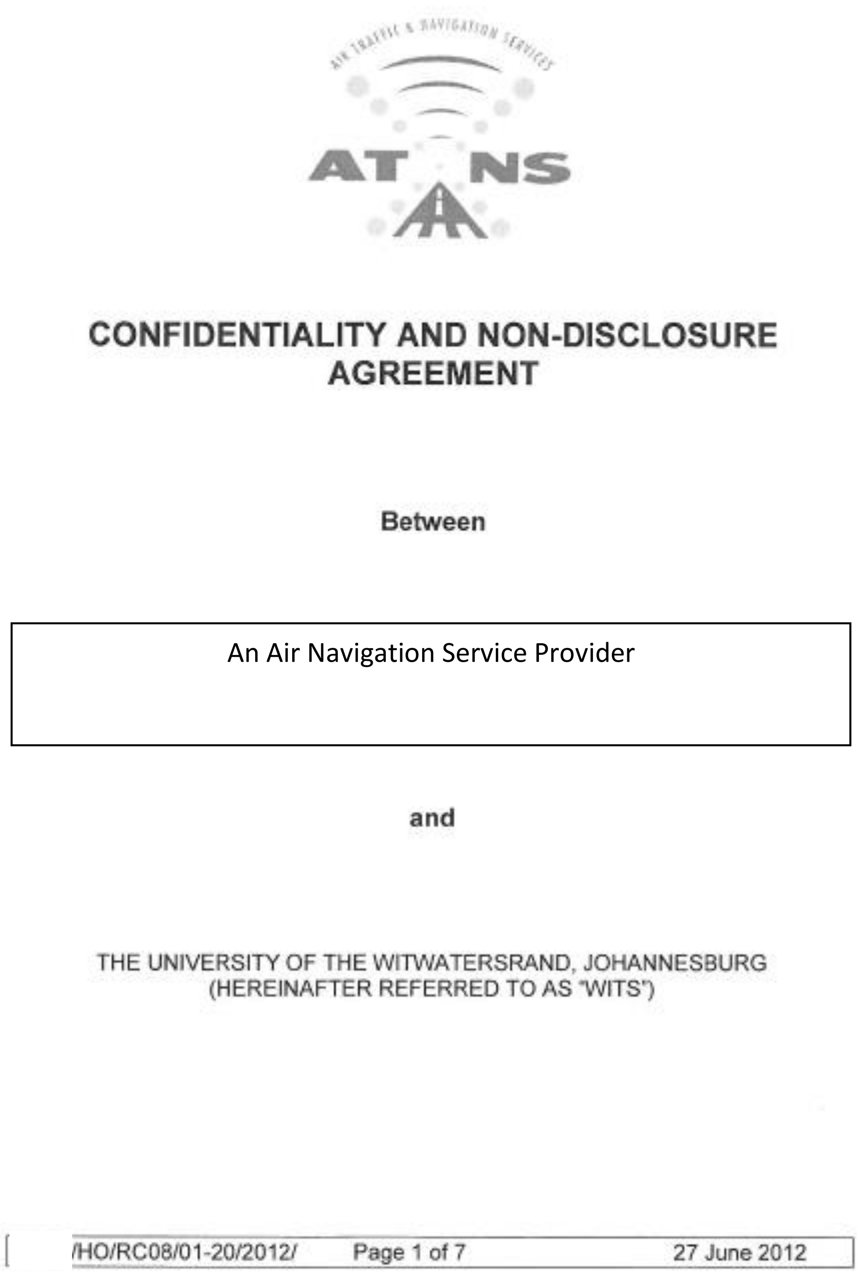
Appendix 1: HERA Model

HERA ANALYSIS							
DESCRIPTION OF ERROR							
1.							
How detected:							
How recovered:							
Causal		**Contributory**		**Compounding**		**Non-contributory**	
HERA CLASSIFICATIONS							
Error Type:							
Error Detail:							
Error Mechanism:							
Information Processing:							
Task Taxonomy:							
Information/ Equipment							
Contextual Condition:							
Reporter's							

Assumptions:		
Analyst's assumptions:		
NOTES		
Source: EUROCONTROL, HERA-JANUS. 2003. HRS/HSP-002-REP-03		

Appendix 2: Non-disclosure agreement.



AIR TRAFFIC & NAVIGATION SERVICES

ATNS

CONFIDENTIALITY AND NON-DISCLOSURE AGREEMENT

Between

An Air Navigation Service Provider

and

THE UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
(HEREINAFTER REFERRED TO AS "WITS")

/HO/RC08/01-20/2012/ Page 1 of 7 27 June 2012

PREAMBLE

WHEREAS:

- intends to share with WITS, confidential Information relating to the mental alertness project;

- The purpose of the information is to enable WITS to conduct the mental alertness project as per Annexure 1:

- the parties agreed that the information to be disclosed is proprietary information, technical knowledge, experience, data of a secret and confidential nature, all of which are regarded by as valuable commercial assets of a highly confidential nature;

- the Parties agree that the disclosure of the ' confidential Information may cause irreparable loss, harm and damage to . Accordingly, the receiving party hereby indemnifies and holds the disclosing party harmless against any loss, action, expense, claim, harm or damage of whatsoever nature suffered or sustained by the disclosing party pursuant to a breach by the receiving party of the provisions of this agreement.

NOW THEREFORE THE PARTIES HEREBY AGREE AS FOLLOWS REGARDING CONFIDENTIAL INFORMATION:

1. INTERPRETATION AND DEFINITIONS

In this agreement: -

clause headings are for convenience only and are not to be used in its interpretation;
unless the context clearly indicates a contrary intention: -

an expression which denotes: -

any gender shall include the other gender;

a natural person shall include a juristic person and vice versa;

the singular shall include the plural and vice versa;

the following words and expressions bear the meanings assigned to them below (and cognate words and expressions bear corresponding meanings): -

1.1 **"agreement"** means the terms and conditions of this agreement;

JE

1.2

1.3 **"confidential information"** means, without limiting the generality thereof, any confidential information, including: -marketing and business plans and strategies, customers, potential customers and business associates; confidential intellectual property including but not limited to discoveries, inventions, designs, processes, know-how, works of authorship, computer software, databases, trade or business names, domain names,, rights (registered or unregistered and applications for same), copyright (including rights in computer software, confidential and proprietary knowledge and information and any rights protecting same; trade secrets including but not limited to, contractual arrangements between each party and its business associates, financial details between each party and its business associates; and matters which relate to the business of either party and in respect of which, information is not readily available in the ordinary course of business to a competitor of the parties, which information may be made or become available to the other party or any personnel thereof pursuant to this agreement;

1.4 **"Disclosing Party"** means the Party disclosing the confidential information;

1.5 **"parties"** means both the and WITS;

1.5 **"Recipient"** means the Party who will be receiving the confidential information and in this instance WITS via Prof. Andrew Thatcher, Dr Fiona Donald, Ms Beverly Slater, and any postgraduate students/assistants that assist with the data collection.

2. USE OF CONFIDENTIAL INFORMATION

2.1 Confidential Information of the Disclosing Party may be used by the Recipient only in connection with the purpose(s) set forth in this agreement. The parties agree to protect the confidentiality of the Disclosing Party's Confidential Information in the same manner they protect the confidentiality of their own proprietary and confidential information, but in any case using reasonable care.

2.2 Except as necessary for the purpose(s) set forth in this agreement, Confidential Information of the Disclosing Party may not be copied or reproduced by the Recipient without the Disclosing Party's prior written consent.

2.3 The Disclosing Party shall in all events remain free to use in the course of its business its general knowledge, skills and experience incurred before, during or after the activities hereunder.

2.4 With respect to the purpose(s) set forth in this agreement, the Recipient is not authorized to use the name, logo or trademarks of the other in connection with any advertising, publicity or marketing or promotional materials or activities without the prior written consent of the Disclosing Party. The Disclosing Party provides the Confidential Information "as is".

2.5 The Recipient shall:

- 1.5.1 treat as strictly confidential any and all Confidential Information given or made known to them arising from this disclosure;
- 1.5.2 keep all such Confidential Information obtained secret towards third parties and only use it for the purpose of the disclosure as expressly agreed upon by the parties;
- 1.5.3 if required, cause all of their employees who are directly or indirectly given access to the said proprietary and Confidential Information to execute secrecy undertakings in a form acceptable to the parties in order to protect the parties against the unauthorised disclosure of such Confidential Information to any third party and to fully co-operate in the enforcement of such secrecy undertakings.

2. OWNERSHIP OF CONFIDENTIAL INFORMATION

2.1 Confidential Information disclosed under this agreement shall at all times remain the property of the Disclosing Party. No license or other rights in or to the material disclosed, is granted by this agreement or any disclosure of Confidential Information under this agreement except as provided herein. All Confidential Information made available under this agreement, including copies thereof, shall be returned to the Disclosing Party upon the first to occur of:

- 2.1.1 completion of the purpose(s) set forth in this agreement; or
- 2.1.2 the reasonable request of the Disclosing Party;
- 2.1.3 cancellation of this agreement.

2.2 Disclosure of Confidential Information shall not constitute any representation, warranty, assurance, guarantee or inducement by the Disclosing Party with respect to infringement of patents or other rights of third parties. No warranty or representation as to the accuracy, completeness, or technical or scientific quality of any Confidential Information is provided herein.

3. EXCLUSIONS

Nothing in this agreement shall prohibit or limit either party's use of information (including, but not limited to, ideas, concepts, know-how, techniques, and methodologies):

3.1 which at the time of disclosure is published or otherwise generally available to the public;

3.2 which after disclosure by the Disclosing Party is published or becomes generally available to the public, otherwise than through any act or omission on the part of the Recipient;

3.3 which the parties can show was in their possession at the time of disclosure and which was not acquired directly or indirectly from each other;

3.4 rightfully acquired from others who did not obtain it under pledge of secrecy to either of the parties;

3.5 which the Recipient is obliged to disclose in terms of an order of court, subpoena or other legal process.

3.6 In the event either party receives a subpoena or other validly issued administrative or judicial process requesting Confidential Information of the other party, the Recipient shall promptly notify the Disclosing Party thereof.

4. BREACH

It is acknowledged that the breach of this agreement by Recipient would cause the Disclosing Party irreparable injury not compensable in monetary damages alone. Accordingly, in the event of a breach, or a threat of a breach, the Disclosing Party, in addition to its other remedies, is entitled to a restraining order, preliminary injunction or similar relief so as to specifically enforce the terms of this agreement or prevent, cure or reduce the adverse effects of the breach.

5. COMMENCEMENT AND DURATION

5.1 This agreement shall operate as from the date of signature hereof.

5.2 The obligation to keep the confidential information secret will survive termination of this Agreement and will remain binding for an indefinite period.

6. GOVERNING LAW

This agreement shall be governed by and construed in accordance with the laws of the Republic of South Africa and any dispute arising there from shall be adjudicated by a competent court in South Africa and for these purposes the parties agree to the exclusive jurisdiction of the South African courts for the adjudication of such disputes.

7. ENTIRE AGREEMENT

This agreement is the only and exclusive agreement between the parties with respect to the subject matter of this agreement, and it supersedes all prior or contemporaneous representations, promises, inducements, proposals, discussions and other communications.

8. PUBLICATION OF INFORMATION FOR ACADEMIC PURPOSES

Notwithstanding anything to the contrary contained herein WITS will be entitled to publish the results of any research arising from the Project in accordance with its rules, regulations, policies and procedures. It will provide with a copy of the proposed thesis, dissertation, manuscript or report pertaining to the Project. will be given a period of thirty (30) days within which to review the proposed manuscript and to notify WITS if it reasonably believes that the intended publication contains information which, if used or published, would result in suffering commercial prejudice. WITS will remove the information that is commercially prejudicial and resubmit the amended publication to on the same conditions as aforesaid. Any successful dissertation, report or thesis that emanates from the Project will be deposited in WITS' library in accordance with its rules, regulations and procedures. may request that access to a thesis, project report or dissertation be restricted for a period not exceeding twelve (12) months, allowing for the possibility of prior securing of intellectual property rights should same exist.

9. GENERAL PROVISIONS

9.1 In the event of a dispute of (which cannot be resolved amicably between the Parties), such dispute will be referred to a Competent Court of Law.

9.2 Any Legal Notice shall be posted in the addresses as mention in the definition clause.

9.3 No public announcement or disclosure beyond those disclosures authorised for Confidential Information hereunder may be made by either party concerning this agreement without the prior written approval of the other party.

9.4 If any clause or term of this agreement should be invalid, unenforceable or illegal, then the remaining terms and provisions of this agreement shall be deemed to be severable therefrom and shall continue in full force and effect unless such invalidity, unenforceability or illegality goes to the root of this agreement.

SIGNED at WITS UNIVERSITY this 12 day of OCTOBER 2012.

AS WITNESSES :

1.

For WITS
Prof. Maria Marchetti-Mercer