AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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MODELS OF AIR TRAFFIC CONTROLLERS ERRORS PREVENTION IN TERMINAL CONTROL AREAS UNDER UNCERTAINTY CONDITIONS

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Abstract

Purpose: *the aim of this study is to research applied models of air traffic controllers' errors prevention in terminal control areas (TMA) under uncertainty conditions. In this work the theoretical framework descripting safety events and errors of air traffic controllers connected with the operations in TMA is proposed.* ***Methods:*** *optimisation of terminal control area formal description based on the Threat and Error management model and the TMA network model of air traffic flows.* ***Results:*** *the human factors variables associated with safety events in work of air traffic controllers under uncertainty conditions were obtained. The Threat and Error management model application principles to air traffic controller operations and the TMA network model of air traffic flows were proposed.* ***Discussion:*** *Information processing context for preventing air traffic controller errors, examples of threats in work of air traffic controllers, which are relevant for TMA operations under uncertainty conditions.*

Keywords: air traffic controller; air traffic services; error management; proficiency skills; safety of flights; terminal control area; uncertainty factors.

1. Introduction

Air traffic control (ATC) service in terminal control areas (TMA) is a highly complex human activity that requires controllers to utilise specific skills/abilities in response to a number of varying unfavourable operational situations/conditions in order to ensure the safe flight of aircraft. Controlled TMA airspaces in most of industrial countries are becoming increasingly crowded with the growth in the number of incidents/accidents caused by the wrong actions/inactions of involved human operators (pilots, air traffic controllers, flight data operators, etc.).

It has been estimated that 60-90 percent of major incidents in complex systems such as aviation are caused by human errors/violations [1]. 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" [2].

The research is focused exclusively on air traffic controller errors and investigates primary impacting variables such as information processing, situation awareness, memory, attention, etc. Identifying the underlying causes of commonly occurring incidents/accidents will help future studies in designing preventive measures that may help eliminate these errors.

A number of factors are explored, with the aim to establish links between the core variables and the safety occurrences in terminal control areas as well as to establish links between the core variables and the uncertainty factors in operation of air traffic controllers [3-5].

2. Analysis of the latest research and publications

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. In research [1] the 'mental workload', which describes the capacity of the operator to meet task demands and physical co-ordination (task demands) is considered.

A number of vulnerabilities inherent in human information processing have been found in ATC [1]. 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, as it discussed in [6].

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". 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, represented in [7].

Memory is a critical factor in establishing effective mental pictures and situation awareness in controllers [8]. Memory is a cognitive function that is fundamental to most of a controller's tasks and is a common thread in most variables. Shorrock [8] 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" [9].

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, proposed in [10].

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" [11]. 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 [12].

Situation awareness (SA) 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 [13]. 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 [14].

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 human-machine interface (HMI). The various models (such as the decision making and SA models) stress the importance of perception and analysis of the environment. The conceptual environmental approach builds on this by recognising the crucial role that environment scanning and perception have on the reciprocal nature of the HMI [15].

3. Safety events and errors of air traffic controllers connected with the operations in TMA

There are two principal safety events that can occur through erroneous Air Traffic Controlling, namely, which are connected with activities in TMA:

– loss of separation (LoS);
– runway incursions (RI).

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 aircraft landing and take-off". 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.

A ***loss of separations*** (LoS) involves an infringement of both horizontal and vertical separation minima in controlled airspace. 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.

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.

There are three distinct types of errors (Fig. 1): 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".

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".

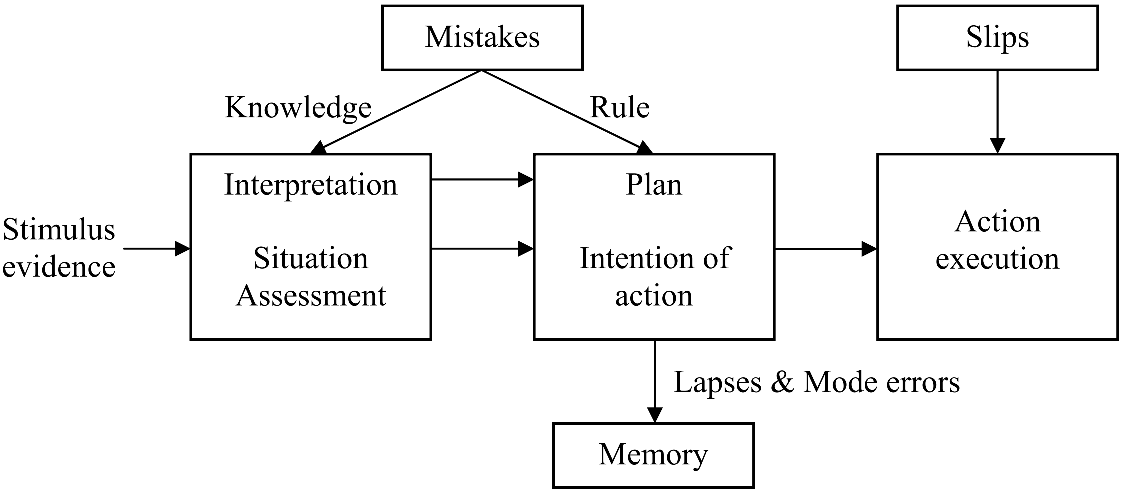

Fig. 1. Information Processing Context for preventing air traffic controller errors

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 [6]. In summary, Reason [6] 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 [6]. Planning failures are classified as mistakes and execution failures as slips or lapses.

The human factors variables, which are associated with safety events in work of air traffic controllers under uncertainty conditions, are divided in such clusters as follows:

1. Information Processing:
– Monitoring failure;
– Information Overload;
– Ambiguous instructions issued;
– Similar call signs;
– Misjudged Aircraft projection.
2. Situation Awareness:
– Erroneous hear-back;
– Misjudged aircraft projection;
– Erroneous Perception;
– Failure to recognize risk;
– Instruction issued to wrong aircraft.
3. Memory:
– Forgot planned action;
– Inaccurate recall of temporary memory;
– Working memory failure;
– Rarely used information.
4. Attention:
– Divided;
– Selective;
– Focused.
5. Human Machine Interface:
– System delay;
– Poor label management;
– Insufficient use of tools.
6. Workload:
– High/Low complexity;
– High/Low volume;
– Underload/Overload;
– Subjective traffic complexity rating;
– Subjective workload rating.

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.

4. The Threat and Error management model application to air traffic controller operations

The Threat and Error Management (TEM) model is a conceptual framework that assists in understanding, from an operational perspective, the inter-relationship between safety and human performance in dynamic and challenging operational contexts.

The TEM model focuses simultaneously on the operational context and the people discharging operational duties in such context. The model is descriptive and diagnostic of both human and system performance.

It is descriptive because it captures human and system performance in the normal operational context, resulting in realistic descriptions. It is diagnostic because it allows quantifying complexities of the operational context in relation to the description of human performance in that context, and vice-versa.

There are three basic components in the TEM model, from the perspective of flight crews: threats, errors and undesired aircraft states. The model proposes that threats and errors are part of everyday aviation operations that must be managed by flight crews, since both threats and errors carry the potential to generate undesired aircraft states.

Flight crews must also manage undesired aircraft states, since they carry the potential for unsafe outcomes. Undesired state management is an essential component of the TEM model, as important as threat and error management. Undesired aircraft state management largely represents the last opportunity to avoid an unsafe outcome and thus maintain safety margins in flight operations.

Table 1 presents examples of threats, grouped under two basic categories derived from the TEM model. Environmental threats occur due to the environment in which flight operations take place. Some environmental threats can be planned for and some will arise spontaneously, but they all have to be managed by flight crews in real time.

Organizational threats, on the other hand, can be controlled or, at least, minimised, at source by aviation organizations.

Table 1

Examples of threats

Environmental Threats	Organizational Threats
Weather: thunderstorms, turbulence, icing, wind shear, cross/tailwind, very low/high temperatures. **ATC:** traffic congestion, TCAS RA/TA, ATC command, ATC error, ATC language difficulty, ATC non-standard phraseology, ATC runway change, ATIS communication, units of measurement (QFE/meters). **Airport:** contaminated/short runway; contaminated taxiway, lack of/confusing/faded signage/markings, birds, aids U/S, complex surface navigation procedures, airport constructions. **Terrain:** High ground, slope, lack of references, “black hole”. **Other:** similar call-signs.	**Operational pressure:** delays, late arrivals, equipment changes. **Aircraft:** aircraft malfunction, automation event/anomaly, MEL/CDL. **Cabin:** flight attendant error, cabin event distraction, interruption, cabin door security. **Maintenance:** maintenance event/error. **Ground:** ground handling event, de-icing, ground crew error. **Dispatch:** dispatch paperwork event/error. **Documentation**: manual error, chart error. **Other:** crew scheduling event

5. The TMA network model of air traffic flows

We divide the airspace into line elements on which we model the density of aircraft. These line elements are called paths and in practice often coincide with jetways. We represent a link on a path as a segment $[0, L]$ and we denote by $u(x,t)$ the number of aircraft between distances 0 and x at time t. In particular, $u(0,t)=0$ and $u(L,t)$ is the total number of aircraft in the path modelled by $[0, L]$ at time t. We make the additional assumption of a steady velocity profile $v(x)>0$ which depicts the mean velocity of aircraft flow at position x and time t. Applying the conservation of mass to a control volume comprised between positions x and $x+h$, and letting h tend to 0, one easily finds the following relation between the spatial and temporal derivatives of $u(x,t)$ [16]:

$$\begin{cases} \dfrac{\partial u(x,t)}{\partial t} + v(x)\dfrac{\partial u(x,t)}{\partial x} = q(t) \\ u(x,0) = u_0(x) \\ u(0,t) = 0 \end{cases} \tag{1}$$

where $q(t)$ represents the inflow at the entrance of the link $(x=0)$ or in terms of the density $q(t) = \rho(0,t)v(0)$.

We can define the density of aircraft as the weak derivative of $u(x,t)$ with respect to x: $\rho(x,t) = \dfrac{\partial u(x,t)}{\partial x}$.

The aircraft density is a solution of the partial differential equation:

$$\begin{cases} \dfrac{\partial \rho(x,t)}{\partial t} + v(x)\dfrac{\partial \rho(x,t)}{\partial x} + v'(x)\rho(x,t) = 0 \\ \rho(x,0) = \rho_0(x) \\ \rho(0,t) = \dfrac{q(t)}{v(0)} \end{cases} \tag{2}$$

This is a linear advection equation with positive velocity $v(x)$ and a source term: $v'(x)\rho(x,t)$. Clearly, these two partial differential equations are equivalent and model the same physical phenomenon.

We now consider a junction with m incoming links numbered from 1 to m and n outgoing links numbered from $m+1$ to $m+n$; each link k is represented by an interval $[0, L_k]$. One can see that any network is composed of a number of such junctions. We define an allocation matrix $M = (m_{ij}(t))$ for $1 \le i \le m, m+1 \le j \le m+n$ where $0 \le m_{ij}(t) \le 1$ denotes the proportion of aircrafts from incoming link i going to the outgoing link j; we should also have $\sum_{j=m+1}^{m+n} m_{ij}(t) = 1$ for $1 \le i \le m$. The system of partial differential equations on the network can be written as [16]:

$$\begin{cases} \dfrac{\partial \rho_k(x,t)}{\partial t} + v_k(x)\dfrac{\partial \rho_k(x,t)}{\partial x} + v'_k(x)\rho_k(x,t) = 0 \\ \rho_k(x,0) = \rho_{0,k}(x) \\ \rho_i(0,t) = \dfrac{q_i(t)}{v_i(0)} \\ \rho_j(0,t) = \dfrac{\sum_{i=1}^{m} m_{ij}(t)\rho_i(L_i,t)v_i(L_i)}{v_i(0,t)} \end{cases} \tag{3}$$

We will now show that on such a network, the preceding system of partial differential equations admits a unique solution hence that the problem is well-posed.

6. Conclusions

In this research we considered the human factors variables, which are associated with safety events in work of air traffic controllers under uncertainty conditions. The threat and error management model was analysed and proposed its application in air traffic controller operations. Also we provided examples of threats in work of air traffic controllers, which are relevant for TMA operations under uncertainty conditions.

Utilisation of the TMA network model of air traffic flow in link with above mentioned models will decrease number incidents/accidents caused by air traffic controllers (and associated personnel) and improve safety of flights.

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Моделі попередження помилок авіадиспетчерів в термінальних диспетчерських районах у умовах невизначеності

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Мета: метою цієї статті є дослідження прикладних моделей попередження помилок авіадиспетчерів у термінальних диспетчерських районах в умовах невизначеності. У роботі запропоновано теоретичні основи формального опису подій з безпеки польотів та помилок авіадиспетчерів, пов’язаних із виконанням технологічних операцій в ТМА. **Методи дослідження:** оптимізація формального опису термінального диспетчерського району, що ґрунтується на моделі управління загрозами та помилками та мережевій моделі потоків повітряного руху в ТМА. **Результати:** отримано показники, пов’язані з подіями з безпеки польотів у роботі авіадиспетчерів в умовах невизначеності. Запропоновано принципи застосування моделі управління загрозами та помилками та мережевої моделі потоків повітряного руху в ТМА. **Обговорення:** середовище обробки інформації для попередження помилок авіадиспетчерів, приклади загроз в роботі авіадиспетчерів, які характерні для виконання технологічних операцій в ТМА в умовах невизначеності.

Ключові слова: авіадиспетчер; безпека польотів; обслуговування повітряного руху; професійно-важливі якості; термінальний диспетчерський район; управління помилками; фактори невизначеності.

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Модели предотвращения ошибок авиадиспетчеров в терминальных диспетчерских районах в условиях неопределенности

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Цель: целью данной статьи является исследование прикладных моделей предупреждения ошибок авиадиспетчеров в терминальных диспетчерских районах в условиях неопределенности. В данной работе предложены теоретические основы формального описания событий по безопасности полетов и ошибок авиадиспетчеров, связанных с выполнением технологических операций в ТМА. **Методы исследования:** оптимизация формального описания терминального диспетчерского района, основанная на модели управления угрозами и ошибками и сетевой модели потоков воздушного движения в ТМА. **Результаты:** получены показатели, связанные с событиями по безопасности полетов в работе авиадиспетчеров в условиях неопределенности. Предложены принципы применения модели управления угрозами и ошибками и сетевой модели потоков воздушного движения в ТМА. **Обсуждение:** среда обработки информации для предупреждения ошибок авиадиспетчеров, примеры угроз в работе авиадиспетчеров, характерные для выполнения технологических операций в ТМА в условиях неопределенности.

Ключевые слова: авиадиспетчер; безопасность полетов; обслуживание воздушного движения; управление ошибками; профессионально-важные качества; терминальный диспетчерский район; факторы неопределенности.

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