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EXECUTIVE SUMMARY

Background

Air traffic controllers (ATCOs) play a vital role to keep air travel safe. Yet the demanding 24/7 nature of their role can lead to fatigue and affect human performance and safety. Fatigue is a known hazard, some level of fatigue is inevitable and must be managed. Commission Regulation (EU) 2015/340 already requires, as part of the ATCOs' licensing scheme, the provision of training on the effects and prevention of fatigue. In 2017, mandatory provisions applicable to Air Traffic Service Providers (ATSP) concerning the prevention and mitigation of ATCO fatigue and stress were introduced with Regulation (EU) 2017/373 and associated Acceptable Means of Compliance (AMC) and Guidance Material (GM).

In 2022, the European Union Aviation Safety Agency (EASA), under tender EASA.2022.HVP.19, commissioned a consortium of leading researchers and fatigue risk management specialists to complete a first-of-its-kind, independent scientific study into ATCO fatigue in Europe. The objective of the research study was "to perform a study on the assessment, prevention and management of occupational fatigue risks, as well as related work environment and operational factors, of ATCOs in the EU, in order to support future decision-making of the EU regulator". The study set out three supporting objectives:

1. To assess the implementation of current EU regulations (2017/373 and 2015/304) relating to ATCO's stress, fatigue, and rostering systems.
2. To conduct research into the prevalence, causes and effects of ATCO fatigue, with a view to collect supporting scientific data and provide guidance on the possible further development of the related EU rules and practices.
3. To assess the potential impacts of future technologies on the ATCO's workload and fatigue.

The research generated a wealth of information across 21 Deliverables, the results of which are summarised hereafter and further detailed in the main parts of this report.

Participation to the study and representativeness

In total, 36 of the 46 EU ATSPs (almost 80%) responded to the initial survey, as well as 240 volunteer ATCOs. A sample of representative ATSPs and of ATCOs was then selected to participate to the following phases of the research, through subjective and objective measurements. With objective data on fatigue, sleep, fatigue factors collected and analysed in 2,416 work sessions, covering 1,414 ATCO duties, the study is based on a strong representativeness and solid scientific methodology and is the first of its kind in the EU.

Main results of the evaluation of the Implementation of the EU Regulations on ATCO fatigue

The study concluded that by 2023 the implementation of the applicable EU requirements on ATCO fatigue throughout the EU Member States has been both effective and efficient, with no significant difficulties observed in the implementation. The total costs for the ATSPs in the 2020 - 2022 period were estimated at €16 million, while an estimated 30 additional ATCOs were recruited across EASA Member States to comply with the ATCO fatigue regulatory requirements. Compared to the situation before the adoption of the ATCO fatigue provisions, the situation has even positively evolved between 2017 and 2023. The analysis of available data indicated that:

- All non-conformities from EASA standardisation inspections related to this topic have been closed.
- 100% of the ATSPs have implemented an ATCO fatigue management policy.
- 88% of the ATSPs have a dedicated fatigue reporting mechanism, while 12% of the ATSPs report through the standard occurrence reporting system under Regulation (EU) 376/2014.

- 100% of the ATSPs declare that they assess fatigue as a potential contributing factor in occurrence investigations and analysis.
- 100% of the ATSPs have procedures in place for the identification and management of the effect of fatigue on operations safety, with 40% of the ATSPs collecting sleep or fatigue data on a quarterly or yearly basis.
- 88% of the ATSPs have included a specific module on fatigue in ATCO training, while 12% of the ATSPs are meeting this requirement only partially.
- 100% of the ATSPs have an information programme for ATCOs on the prevention and effect of fatigue.

While the requirements appear to be fulfilled, the ATCO representatives stressed that these measures are often either insufficient or ineffective in practice.

The ATCO fatigue regulatory requirements have helped to achieve a more homogenous framework for the prevention and mitigation of ATCO fatigue. However, from the study it appeared that there are qualitative differences in the way that the ATSPs have implemented the ATCO fatigue regulatory requirements. Regarding the rostering systems, differences appeared between the values used by the ATSPs for the eight roster elements defined in the Regulation 2017/373. In the report the average maximum and minimum values for the roster elements based on the data collected from the survey with the 36 participating ATSPs are as follows:

Average values and standard deviation for roster elements (2023)	**Area Control Centre (ACC)** Average	**Area Control Centre (ACC)** Standard deviation	**Aerodrome (TWR)** Average	**Aerodrome (TWR)** Standard deviation
(1) maximum consecutive working days with duty (days)	5.9	1.4	5.8	1.7
(2) maximum hours per duty period (hours)	9.2	3.0	10.5	2.7
(3) maximum time providing air traffic control service without breaks (minutes)	90	38	154	89
(4) ratio of duty periods to breaks when providing air traffic control service	0.69	0.10	0.72	0.10
(5) minimum duration of rest periods (hours)	11.6	5.3	12.0	5.1
(6) maximum consecutive duty periods encroaching the night-time (days)	2.3	1.0	2.9	1.2
(7) minimum rest period after a duty period encroaching the night-time (hours)	22.5	19.5	17.8	15.5
(7) minimum rest period after a duty period encroaching the night-time (hours)	3.7	2.0	3.7	4.5

No ATCO fatigue-related accident or serious incident have been reported in the last ten years in the EASA Member States (incl. United Kingdom until 2020). Data from the European Central Repository (ECR) on ATCO fatigue-related occurrences was analysed, and only 184 incidents related to ATCO fatigue were found between 2013 and 2022. However, there is insufficient detailed information in that data sample to analyse occurrences in relation to fatigue risk management and rostering practices. It was indeed observed that the ECR data sample of ATCO fatigue-related occurrences lacked good quality of reporting and completeness. In addition, biases in reporting were evident. In the present study, these issues limited the detailed (statistical) analyses and affected the usability and statistical validity of the safety data analysis results. It cannot be ascertained that the results represent all EASA Member States. It is recognised that ATCO fatigue reporting is an area that will likely mature over time as reporting becomes normative practice, but more guidance and fatigue reporting promotional activities could be considered.

Moreover, the study highlighted that the fatigue reporting mechanisms and training/information programs are not fully effective. In addition, variance across ATSPs in the EASA Member States in the values of the eight roster elements were observed as a result of national regulations and local practices. Guidance to achieve a better level-playing field on work and rostering practices could be considered for the future.

Some stakeholders indicated that they need more guidance concerning reference values for roster elements and working time. In addition, the study highlighted that some terms and definitions are not equally understood and applied across ATSPs, which may require more precise definitions or clarification.

Main results on the ATCO fatigue prevalence, causes and effects

The extensive literature review highlighted that the current scientific knowledge regarding ATCO fatigue in the EU is very limited. The majority of the existing studies were conducted outside of the EU and used a relative small number of participants, while those conducted in the EU were mostly based on empirical methodologies.

The data collection and analysis was performed through successive methodological steps: a roster analysis (24 actual rosters) with two bio-mathematical models (BMMs), subjective fatigue measurements for 10 consecutive days with questionnaires through an application, objective fatigue measurements in the ops room during shifts using actigraphy, continuous eye tracking and a pre- and post-duty performance tests (PVT). The objective measurements confirmed that the subjective fatigue ratings used were valid indicators for ATCO fatigue.

The data collection and analysis revealed that most of the rosters were based on a clockwise, fast-paced cycle rotation and provide already today sufficient opportunities for sleep and recovery. A critical level of fatigue was observed for 5.6% of the duties, which is considered as corresponding to a **low to moderate fatigue risk** relative to other relevant professional domains. This therefore suggests that the current practices of EU ATSPs in terms of fatigue management are quite effective in terms of controlling fatigue risk. The study identified also the most critical factors for fatigue, both roster- and non-roster-related, that should be managed by the ATSPs and calculated a fatigue risk index associated to these factors. This index represents the percentage of risk increase compared to the baseline, constituted by the average values observed (see table above).

Three of the eight mandatory roster elements create relatively high risks of critical fatigue:

- Maximum time providing ATS services without breaks: each additional hour increases the risk of critical fatigue by +33% for every additional hour in one work session.
- Consecutive work days with duty increase the risk by +27% for every additional working day.
- Minimum number of rest periods within a roster cycle reduces the risk by -43% for each additional day of rest following a duty encroaching night-time.

The study could not gather data for the other five mandatory roster elements, probably because they are correctly implemented today and do not trigger specific risks.

The other top contributing fatigue factors, non- rosters-related include:

- Night duties significantly increase the risk of critical level fatigue by 253%.
- Difficult weather conditions increase the risk of critical level fatigue by +192%.
- Monotonous traffic situations increase the risk by +120%.
- Every additional 10% of sleep debt increases the risk of critical fatigue by 80%.

It was observed that evening duties reduce the risk of critical fatigue by 25% and that each additional day of rest following a duty encroaching night time reduces the risk of critical fatigue by 43%.

With regards to other contributing factors to fatigue, the results of the study showed:

- Age showed to have a marginal effect on fatigue.
- Gender, work experience, and job position did not significantly impact fatigue.
- ATCO workload increased fatigue moderately.
- Difficult coordination between ATCOs, had a significant but low impact on fatigue.

Main results on the prevention and management of ATCO fatigue in the operational environment

The research showed that preventing and reducing ATCO fatigue requires a multi-layered and comprehensive approach. This report presents recommendations and guidance to support the ATSPs and ATCOs in the prevention and management of fatigue risks in the operational environment and within their organisation. It provides good practices and guidance that can be used for implementing and developing a Fatigue Risk Management System (FRMS), notably on reactive, proactive and predictive FRMS processes. This includes the rostering system itself and practical guidance for roster planning to mitigate roster-related fatigue factors, e.g. the application of scientific guidance for roster analysis and good practices on the use of biomathematical models in pre- and post-roster publication. Additionally, practical guidance is provided on fatigue reporting, occurrence investigation in relation to ATCO fatigue and good practices for the use of fatigue reports. In addition to the FRMS processes and rostering system, ATSPs can also consider the six following operational interventions, identified as the potentially most efficient measures to prevent and reduce ATCO fatigue: implementing an FRMS with structured mitigations, providing sleeping facilities and opportunities near operations rooms, education programmes, the use of napping pre-duty and, where appropriate, the use of napping on breaks during duty. The specific culture within each ATSP, the needs and wishes of the target population, and the individual characteristics of the ATCOs will of course influence the implementation.

10 Key Recommendations from the study

The key recommendations to EASA are:

- Achieve a better level-playing field on work and rostering practices and reduce some of the extreme variance across EU ATSPs (thereby suppressing the few current critical fatigue hotspots).
- Clarify the terminology and definitions where required in the appropriate material, e.g. ‘rest periods’, ‘rest breaks’, ‘night-time’, ‘working time/hours’, and definition of different shift types.
- Address the concerns expressed by the ATCO associations on the effectiveness of the fatigue reporting mechanisms and the ATCO fatigue information programmes at local level.
- Improve mandatory reporting through the ECR/ECCAIRs: strengthen oversight on the implementation of applicable EU Regulations, in particular Regulation 376/2014 and consider improvements to the ECR and ECCAIRs reporting tools and search fields, where needed. It is recommended that the EU authorities investigate the reasons why the quality and completeness of the ECR database in ATCO-fatigue related occurrences is not optimal, and make the necessary improvements.
- Invite ATSPs to assess the guidance and good practices described in this report, for the development of their rosters, fatigue risk management and FRMS. In particular ATSPs should:
  - consider the average values of the various rostering parameters and related risk factors identified in the study;
  - assess the fatigue risks in their own working practices; and
  - identify priority risk factors in their rosters and adapt their practices.
- Invite ATSPs to consider implementing a FRMS including reactive, proactive and predictive FRMS processes, as proposed in this study report.
- It is recommended to further evaluate the feasibility and validation of (new) objective fatigue monitoring technologies (for instance wireless EEG, speech analysis and web-cam based eye tracking) in the control room since they could make it possible to monitor fatigue continuously and in a non-intrusive manner, taking due consideration of ethical and data privacy issues.

- Develop policy measures to ensure and facilitate appropriate consideration of ATCO fatigue and fatigue hazards in the development and implementation of (future) ATCO supporting technologies. The guidance described in this report may be used as a starting point.
- Promote dissemination and knowledge sharing on ATCO fatigue, and thereby support increased awareness and know-how about the prevalence, causes and impact of ATCO fatigue amongst all stakeholders.
- Although this study tackled some of the knowledge gaps, consider further research in ATCO fatigue. The study has identified several topics for which additional, experimental research, using simulations for instance, would be useful to complement some of the study results.

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ABBREVIATIONS

ACRONYM	DESCRIPTION
ACC	Area Control Centre
ADREP	Accident/Incident Data Reporting
AIB	Accident Investigation Bureaus
AMC	Acceptable Means of Compliance
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
APP	Approach
ATC	Air Traffic Control
ATCEUC	Air Traffic Controllers European Unions Coordination
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Services
ATSP	Air Traffic Service Provider
ATSU	Air Traffic Services Unit
BMM	Bio Mathematical Model
CAA	Civil Aviation Authority
CAAi	CAA International
CAG	Collaborative Action Group
CANSO	Civil Air Navigation Services Organization
CBT-I	Cognitive Behavioural Therapy for Insomnia
CWP	Controller Working Position
EAAP	European Association for Aviation Psychology
EASA	European Union Aviation Safety Agency
EC	European Commission
ECCAIRS	European Co-ordination Centre for Accident and Incident Reporting Systems
ECR	European Central Repository
EEG	Electroencephalogram
ETF	European Transport Workers Federation
EU	European Union
FAA	Federal Aviation Administration
FAID	Fatigue Assessment Tool by InterDynamics
fNIRS	functional near-infrared spectroscopy
FRM(S)	Fatigue Risk Management (System)
FSAG	Fatigue Safety Action Group
GDPR	General Data Protection Regulation
GM	Guidance Material

HILT	Human In The Loop
HPA	Human Performance Assessment
ICAO	International Civil Aviation Organization
IFATCA	International Federation of Air Traffic Controllers’ Associations
ISA	Instantaneous Self-Assessment of Workload
KPI	Key Performance Indicator
KSS	Karolinska Sleepiness Scale
MAB	Member States Advisory Body
NAA	National Aviation Authority
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NLR	Royal NLR – Netherlands Aerospace Centre
NS	Not Significant
NSA	National Supervisory Authority
OPS	Operations
PERCLOS	PERcentage of eyelid CLOsure
PoC	Point of Contact
PVT	Psychomotor Vigilance Task
RSME	Rating Scale Mental Effort
RT	Reaction Time
SAFTE-FAST	Sleep, Activity, Fatigue, and Task Effectiveness - Fatigue Avoidance Scheduling Tool
SESAR	Single European Sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
SID	Standard Instrument Departure
SMS	Safety Management System
SP	Samn-Perelli (Fatigue Scale)
SPAM	Situation Present Assessment Method
SSS	Stanford Sleepiness Scale
STAR	Standard Arrival Route
SWIM	System-wide Information Management
TCAS RA/TA	Traffic alert and Collision Avoidance System Resolution Advisory / Traffic Advisory
TeB	Technical Bodies
TeC	Technical Committees
TLX	Task Load Index
TNA	Training Needs Analysis
TRL	Technology Readiness Level
TWR	Tower
UK	United Kingdom
US	United States of America
USAF	United States Air Force

GLOSSARY

Fatigue: There is no unique definition of fatigue. However, it is acknowledged that it is a multifactorial concept associated with different causes (fatigue factors) and consequences (e.g. sleepiness, reduced performance, impaired mood). In 2016, ICAO has defined fatigue as a "*physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties"* (ICAO, 2016). Almost the same definition is being used in EU regulation 2017/373[1] (Fatigue means a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase or workload (mental or physical activity, or both) that can impair an individual's alertness and ability to safely perform his/her tasks). In the current study, this definition is also applied.

Fatigue Risk Management (FRM): Fatigue risk management refers to organisational activities to manage fatigue. Fatigue Risk Management (FRM) processes are one part of the day-to-day operations of the FRMS (ICAO, 2016).

Fatigue Risk Management System (FRMS): A data-driven means of continuously monitoring and managing fatigue related safety risks, based upon scientific principles, knowledge and operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness (ICAO 2016). FRMS covers the management system in place with the organisational processes to manage fatigue in a systematic manner, including policy, setting objectives, action plans, assurance and promotion activities etc.

Break: Break means a period of time within the duty period when an air traffic controller is not required to perform duties, for recuperation purposes (Regulation (EU) 2017/373).

Sleepiness: Fatigue and sleepiness are often used interchangeable, but sleepiness predominantly refers to the combined effect of sleep homeostasis factors, which increases linearly throughout the day after waking, and circadian factors, which are especially responsible for increasing sleepiness in the early hours of the morning, and not so much about reduced performance as a result of mental and/or physical activity (Phillips, 2015).

Drowsiness: Drowsiness is closely related to sleepiness, and has been defined as a state of impaired awareness which is associated with a desire or inclination to sleep. It is associated with slowed reaction times, reduced vigilance, and deficits in information processing including difficulties in integrating information and decreased accuracy of short-term memory (Slater, 2008).

Duty: Duty means any task that an air traffic controller is required to perform by the air traffic control service provider (Regulation (EU) 2017/373).

Duty period: Duty period means a period which starts when an air traffic controller is required by the air traffic control service provider to report for or be available for or to commence duty and ends when the air traffic controller is free from duty.

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[1] Commission Implementing Regulation (EU) 2017/373 of 1 March 2017, Annex I (48).

Rest period: Rest period means a continuous and defined period of time, subsequent to and/or prior to duty, during which an air traffic controller is free of all duties (Regulation (EU) 2017/373).

Rostering system: Rostering system means the structure of duty and rest periods of air traffic controllers in accordance with legal and operational requirements (Regulation (EU) 2017/373).

Shift: See Duty.

Sleep debt: Sleep debt means sleep loss accumulated when sleep is insufficient for multiple nights (or 24-hr days) in a row. As cumulative sleep debt builds up, performance impairment and objective sleepiness increase progressively, and people tend to become less reliable at assessing their own level of impairment (ICAO, 2016).

Working session: One work session is defined as a period of continuous work; two or more work sessions, usually separated by a break, form one operational duty.

1. Introduction

1.1 Background

The aviation industry provides one of the safest modes of transport, and there is a continuous drive to actively manage known and emerging hazards which have the potential to degrade safety. Fatigue is a known hazard that impacts human performance and can be a contributing factor to different types of occurrences, even potentially accidents. Air Traffic Control Officers (ATCOs) have shift patterns rostered to provide services in a 24/7 environment. Therefore, in view of it potential impact on safety, this topic needs to be assessed, monitored and addressed by competent authorities.

Commission Implementing Regulation (EU) 2015/340 of 20 February 2015 requires, as part of the ATCOs' licensing scheme, the provision of training on the effects and prevention of fatigue. In 2017, mandatory provisions applicable to ATS providers (ATSP) concerning the prevention and mitigation of ATCO fatigue and stress were introduced with Commission Implementing Regulation (EU) 2017/373 of 1 March 2017 and associated Acceptable Means of Compliance (AMC)[2] and Guidance Material (GM)[2].

In 2022, five years after the introduction of such requirements, EASA wished to comprehensively assess how Member States and their Air Traffic Service Providers (ATSPs) have implemented these provisions and take stock of the current EU landscape in this field. In this context, it was opportune to collect scientific data and undertake dedicated research, with a view to support decision-making on a possible further development of the existing EU regulatory framework on this matter. Finally, the potential impact of new innovative technologies on ATCOs' occupational health and working conditions needed to be assessed, in the context of the rapid development of automation in ATM/ANS.

EASA contracted a consortium to perform this research study on the impact analysis, prevention and management of ATCO fatigue in the European Union. The consortium is led by the Dutch aerospace research organisation NLR and Welbees, and supported by consortium partners including, Ries Simons Consulting, Ecorys Netherlands, MovingDot and CAA International.

1.2 Main objectives

The objective of this research study is to perform a study on the assessment, prevention and management of the occupational fatigue risks, as well as related work environment and operational factors, of ATCOs in the EU, to support future decision-making of the EU aviation regulator. To support this overall objective, EASA defined three main supporting tasks:

1. Assess the implementation of existing ATCO fatigue EU regulatory requirements, notably:
    a. Commission Implementing Regulation (EU) 2015/340[3] laying down technical requirements and administrative procedures relating to air traffic controllers' licences and certificates, was adopted on 20 February 2015 and applied from 30 June 2015. Commission Implementing

[2] Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-ATS. Specific requirements for providers of air traffic services (ATS). Initial Issue, 8 March 2017. Annex IV to ED Decision 2017/001/R.

[3] Commission Regulation (EU) 2015/340 of 20 February 2015 laying down technical requirements and administrative procedures relating to air traffic controllers' licences and certificates pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council, amending Commission Implementing Regulation (EU) No 923/2012 and repealing Commission Regulation (EU) No 805/2011.

Regulation (EU) 2015/340 imposes, as part of the ATCO's licensing scheme, training on human factors which includes a programme on the prevention of fatigue.

b. Commission Implementing Regulation (EU) 2017/373[4] adopted on 1 March 2017 and applied as of January 2020 imposes several requirements on air traffic service providers linked to ATCO fatigue, notably specific human factors requirements related to stress, fatigue and rostering, as part of their safety management systems. The Regulation contains a number of mandatory requirements for ATSPs aimed at preventing ATCO fatigue; among other requirements, it mandates ATSPs to specify within their rostering system a minimum of eight elements, linked to the ATCO working times. No values are prescribed for these elements. The Regulation is completed by Acceptable Means of Compliance and Guidance Material.

2. Conduct comprehensive, objective and scientific data collection in the area of ATCO fatigue to support the assessment of the fatigue prevalence, causes and mitigation measures;.
3. Assess the possible impact of the introduction of new technologies on ATCOs' workload and fatigue.

1.3 Guidance for the reader

This final report provides an overview of the study and summarises the research activities, main findings, conclusions and recommendations. Figure 1-1 illustrates the report's main structure and the three main parts that will be covered in the report.

Part I – Evaluation of the implementation of the EU Regulations on ATCO Fatigue
In the first part, the report covers the results, conclusions and recommendations stemming from the review of the implementation of ATCO fatigue-related provisions by 36 ATSPs providing services in the EASA Member States. The objective of this part of the study was to assess how ATSPs have implemented the regulatory requirements on ATCO fatigue in 2023 compared to the situation in 2017. In addition, the review of existing scientific knowledge in literature regarding ATCO fatigue, and the review of historical ATCO fatigue-related occurrences is presented. The first part of the report ends with conclusions and recommendations related to the implementation of ATCO fatigue regulatory requirements, the current scientific knowledge and ATCO fatigue-related occurrences.

Part II – ATCO fatigue prevalence, causes and effects in actual operations
In the second part, the report presents the results of the comprehensive, objective and scientific data collection and research. It describes the research approach and provides an overview based on the analysis of actual rosters and data collected in subjective and objective measurement campaigns with the voluntary participation of 236 ATCOs in a representative sample of European ATSPs.

Part III – ATCO fatigue management in the future
Finally, the third part of the report provides good practices and guidance to support ATSPs and ATCOs in the management of ATCO fatigue in the operational environment, including through Fatigue Risk Management Systems (FRMS), fatigue risk management processes, and practical means to prevent and manage ATCO fatigue. In addition, it addresses the potential impact of ATCO supporting technology on ATCO workload and fatigue, covering benefits and potential hazards for ATCO fatigue. The report ends with a summary of the key conclusions from the entire study and lists key recommendations to EASA.

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[4] Commission Implementing Regulation (EU) 2017/373 of 1 March 2017 laying down common requirements for providers of air traffic management/air navigation services and other air traffic management network functions and their oversight, repealing Regulation (EC) No 482/2008, Implementing Regulations (EU) No 1034/2011, (EU) No 1035/2011 and (EU) 2016/1377 and amending Regulation (EU) No 677/2011.

PART I: Evaluation of the implementation of the EU Regulations on ATCO Fatigue

Chapter 2 - 4

- How have ATSPs implemented the ATCO fatigue-related regulations in 2023 compared to 2017?
- What was the impact in terms of effectiveness, efficiency and added value?
- What is the existing knowledge on ATCO fatigue in scientific literature?
- What do we learn from the analysis of historical ATCO fatigue-related occurrences?
- What opportunities for improvement have been identified in the study?

PART II: ATCO fatigue prevalence, causes and effects in actual operations

Chapter 5

- What are the current working practices in EU ATSPs?
- What is the ATCO fatigue prevalence in actual operations?
- What is the level of exposure to critical fatigue in actual operations?
- What are the sources for fatigue and critical level of fatigue?
- What is the impact of roster-related factors on fatigue?
- What is the impact of operational factors on fatigue?

PART III: ATCO fatigue management in the future

Chapter 6

- What fatigue prevention and mitigation measures can ATSPs adopt?
- Guidance to advance FRMS and fatigue risk management processes
- Guidance on roster elements and rostering system
- Good practices for fatigue reporting and investigating fatigue in occurrences
- What are effective operational measures to prevent and mitigate ATCO fatigue?

Chapter 7

- What added value may ATCO supporting technologies bring for ATCO workload and fatigue?
- What hazards do future technologies bring for ATCO workload and fatigue?
- Guidance to cover ATCO fatigue in technology development

Chapter 8

- What are the main conclusions from the study?
- What are the key recommendations from the study?

Figure 1-1: Guidance for the reader.

Part I: Evaluation of the Implementation of the EU Regulations on ATCO Fatigue

2. Evaluation of the implementation of ATCO fatigue-related regulatory requirements

2.1 Introduction

The research study evaluated how ATSPs in the EASA Member States[5] have implemented EU ATCO fatigue-related regulatory requirements in 2023, and to compare that to the situation in 2017. The effectiveness, efficiency and added value of the ATCO fatigue-related regulatory requirements for the different types of air traffic control provisions and operational environments were assessed.

Data was collected using:

- A survey targeted at all ATSPs in the EASA Member States (response rate 78%).
- A survey targeted at all National Supervisory Authorities (NSAs)/National Aviation Authorities (NAAs) (response rate 33%).
- Interviews with a representative sample of 18 ATSPs[6].
- Written responses to open questions provided by ATCO associations (Air Traffic Controllers European Unions Coordination (ATCEUC), European Transport Workers Federation (ETF) and International Federation of Air Traffic Controllers' Associations (IFATCA)).

In addition, desktop research covered applicable regulations on ATCO fatigue, guidance material developed by several organisation, results from EASA standardisation inspections and ATCO fatigue policies and related documentation from a sample of ATSPs collected during the interviews. More information on the approach is provided in Annex C , and detailed results and substantiation of the conclusions in the study deliverables D-1.A.2 & D-1.B.

2.2 ATCO fatigue-related regulatory requirements

One of the essential requirements in the 2018/1139 Basic Regulation of 4 July 2018 states that: *"ATC service provision shall not be undertaken unless the following conditions are met: (a) the prevention of fatigue of personnel providing an ATC service shall be managed through a rostering system. Such a rostering system needs to address duty periods, duty time and adapted rest periods. Limitations established within the rostering system shall take into account relevant factors contributing to fatigue such as, in particular, sleep deprivation, disruption of circadian cycles, night hours, cumulative duty time for given periods of time and also the sharing of allocated tasks between personnel;"[7].*

As a consequence of this essential requirement in the Basic Regulation, specific requirements on ATCO fatigue were included in Commission Implementing Regulation 2017/373, adopted on 1 March 2017 and applied as of January 2020. Acceptable Means of Compliance (AMC) and Guidance Material (GM) is provided in "Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-ATS, Specific requirements for providers of air traffic services (ATS), Initial Issue, 8 March 2017 (Annex IV to ED Decision 2017/001/R)". In Annex IV (Part-ATS), Subpart A (Additional Organisation Requirements for Providers of Air Traffic Services (ATS.OR)), section 3, specific human factors requirements for air traffic control service providers are provided. In this section, requirements ATS.OR.300 (Scope), ATS.OR.315 (Fatigue) and ATS.OR.320 (Air traffic controllers' rostering

[5] The scope of the study was limited to ATSPs having their principal place of operation in the EASA Member States. The 5 non-EU ATSPs providing services in the EASA Member States were not included.

[6] See for substantiation of the representativeness of the sample of ATSPs the study deliverable D-1.A.1.

[7] Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency. See Annex VIII, Essential requirements for ATM/ANS and air traffic controllers. Article 5.2 (a) on Service providers and training organisations.

system(s)) impose specific requirements linked to ATCO fatigue. These requirements are accompanied with Acceptable Means of Compliance (AMCs) and Guidance Material (GM).

In addition, Commission Regulation (EU) 2015/340 requires that, as part of the ATCO's licensing scheme, training on human factors includes a programme on the prevention of fatigue. Regulation (EU) 2015/340 was adopted on 20 February 2015 and while theoretically applicable from 30 June 2015, was actually implemented by EU ATSPs as of 2017 only.

In this report, the requirements related to ATCO fatigue in Regulation (EU) 2017/373 and Regulation (EU) 2015/340 are referred to as the "***ATCO fatigue regulatory requirements***". These requirements consist of the following main elements:

(1) The establishment of an <u>ATCO fatigue management policy</u> (see ATS.OR.315(a) and AMC1 ATS.OR.315(a)).
(2) Principles and procedures to enable <u>fatigue reporting</u> (see AMC1 ATS.OR.315(a)).
(3) <u>Fatigue in occurrence investigation and analysis</u>: Principles and procedures for occurrence investigation and analysis to consider fatigue as contributing factor (see AMC1 ATS.OR.315(a)).
(4) Procedures for the <u>identification and management of the effect of fatigue on safety</u> (see AMC1 ATS.OR.315(a)).
(5) The prevention of <u>fatigue is included in the training programme</u> as part of the ATCO's licensing scheme (see Commission Regulation (EU) 2015/340).
(6) ATCO fatigue <u>information programme</u> (see ATS.OR.315(b)).
(7) ATCO <u>rostering system</u> to manage the risks of occupational fatigue of ATCOs in which 8 elements have been specified (see ATS.OR.320 and AMC1 ATS.OR.320(a)(6);(7)).

2.3 ATSPs and ATCOs in the EASA Member States

This study covers all 46 ATSPs designated to provide air traffic services in the EASA Member States[8]. These ATSPs exhibit diversity in terms of the services they offer, their size, and ownership structures. The ATSPs provide air traffic services from Area Control Centres (ACC), Approach Control Centres (APP) or Aerodrome Control Towers (TWR), or all. In this study, 'ACC' refers to a (radar) control centre from which area control services (ACC) and/or approach control services (APP) are provided, depending on the designation by the Member State[9]. The services provided from a aerodrome have been addressed in a separate category, referred to as 'TWR'.

Figure 2-1 shows the distribution of EU ATSPs by service provision. In total, 31 ATSPs (67%) provide services both at ACCs and aerodromes (TWRs) within an EASA Member State. One intergovernmental organisation (Eurocontrol) provides cross-border air traffic services in multiple EASA Member States from one ACC (MUAC). 14 ATSPs (31%) only provide air traffic services at aerodromes. Four of these 14 organisations provide air traffic services at more than one aerodrome, while the remaining 10 ATSPs provide air traffic services at only one aerodrome.

[8] Third countries ATSPs designated to provide services in the EASA Member States have been excluded from the scope of this study, due to the fact that they may be subject to different legislations.
[9] In most cases APP is included in the centre from which ACC is provided. For the smaller ATSPs we observed that APP is combined with TWR (approach control services are provided from the TWR).

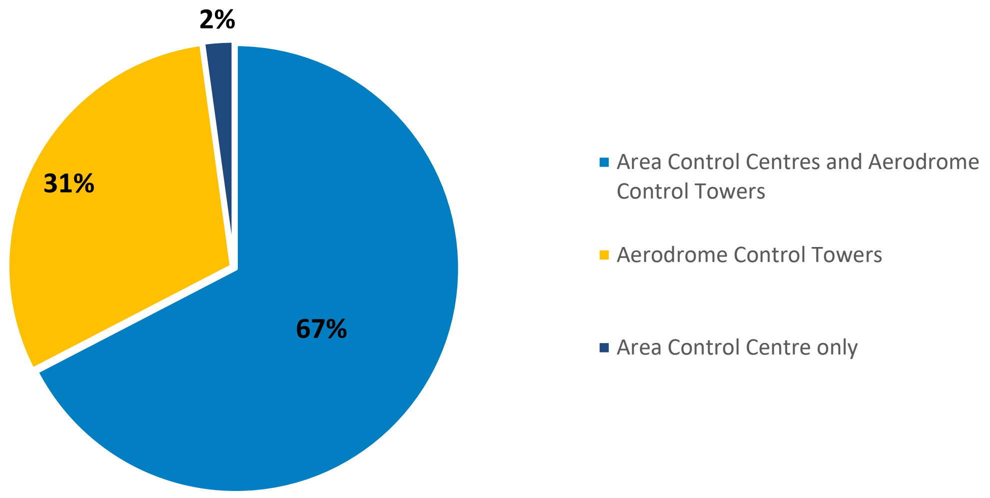


Figure 2-1: The distribution of ATSPs by service provision.

Around 16,400 ATCOs are employed by ATSPs in the EASA Member States. In 2020, 72.9% of the ATCOs were male, and 27.1% were female (EASA, 2022). Figure 2-2 shows the age profile, expressed by the distribution (in percentages) of the following age intervals of 10 years: <= 30, 31-40, 41-50, 51-60, >60. The European average for ATCOs are presented below for 2020 (EASA, 2022).

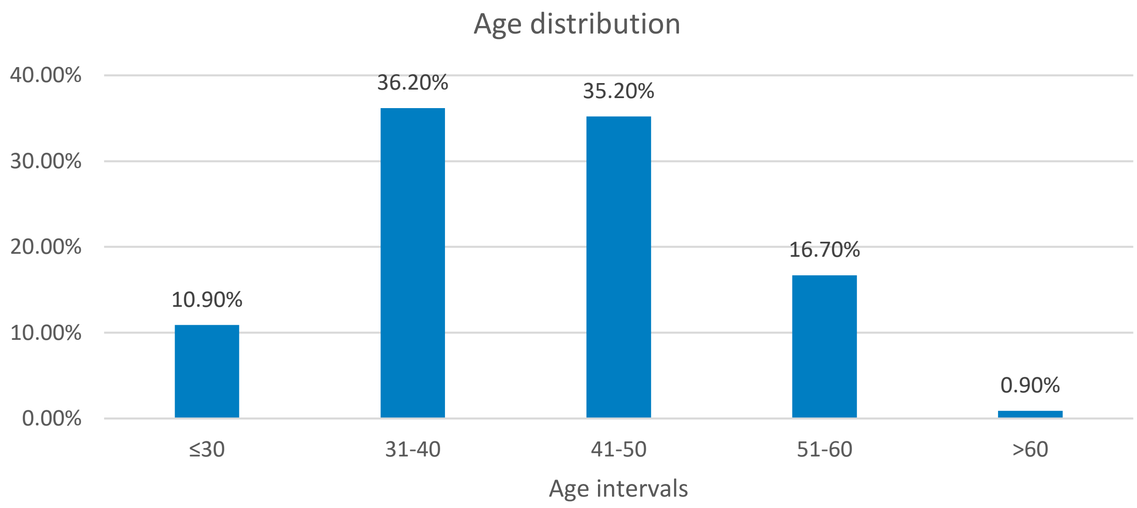


Figure 2-2: European average age profile of ATCOs in 2020.

The ATSPs vary in the number of ATCOs employed. The smallest ATSP employs two ATCOs, while the largest ATSP employs 3,650 ATCOs. Figure 2-3 shows a classification of ATSPs according to the number of ATCOs and type of organisation. Around 30% of the ATSPs employ 50 ATCOs or less; 35% employ between 50 and 250 ATCOs; 17% employ between 250 and 500 ATCOs; and 17% of the ATSPs employ more than 500 ATCOs. The number of ATCOs of four of the ATSPs could not be determined. It has been assumed that these ATSPs employ 50 ATCOs or less.

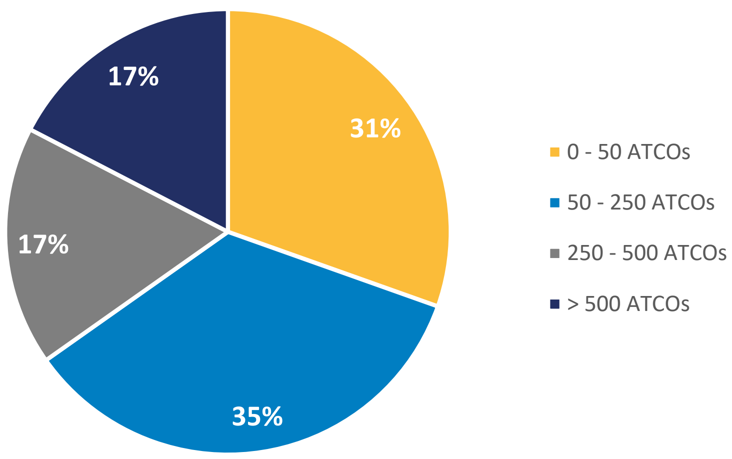


Figure 2-3: ATSPs classified on the basis of the number of ATCOs.

Figure 2-4 shows the employment of ATCOs by the ownership of the ATSP. 75% of the ATCOs work in a state-owned ATSP, 23% of the ATCOs work in a private organisation, and the remaining 2% of ATCOs work for a government-owned ATSP. Figure 2-5 shows ATCO employment within the EU by organisation type.

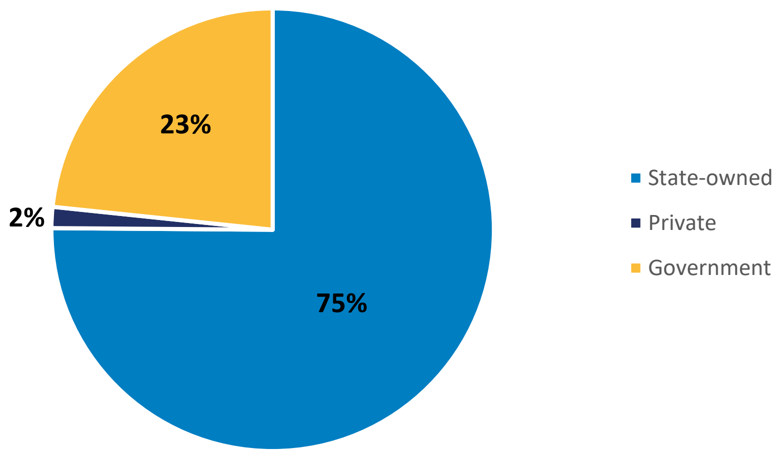


Figure 2-4: Employment of ATCOs by ownership of ATSP.

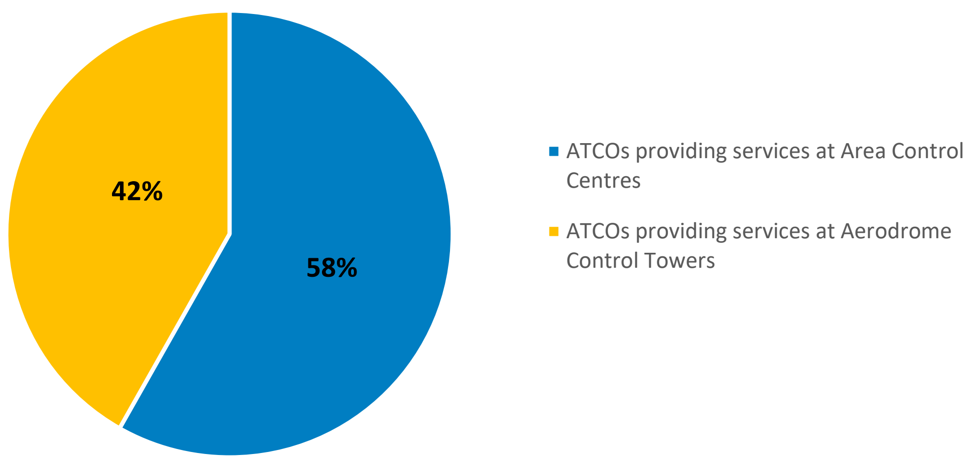


Figure 2-5: ATCO employment classified on the basis of organisation type.

As illustrated in Figure 2-6, most of the ATSPs in the EASA Member States (61%) are corporatised and fully State-owned. The Maastricht Upper Area Control Centre (MUAC) is Europe's only intergovernmental multinational cross-border ATSP. MUAC manages the upper airspace over Belgium, the Netherlands, Luxembourg and North-West Germany. One-third of the ATSPs (33%) are private companies. Within this group of private companies, some ATSPs provide services at only one aerodrome. In contrast, others provide services at multiple aerodromes, which in some cases are located in different EASA Member States. No private ATSPs considered in this study provide services at ACCs. The private companies are generally small. Only two of the 15 private ATSPs employ more than 50 ATCOs. It is estimated that 2% of the ATCOs are employed by a private company. The employment per type of organisation is presented in the inner circle of Figure 2-6.

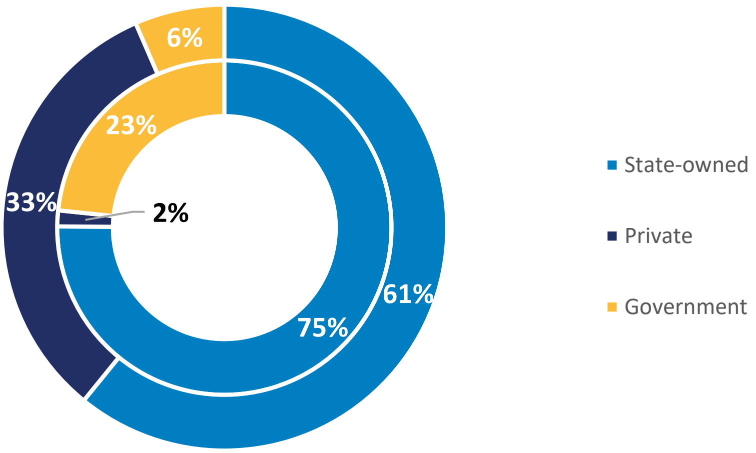


Figure 2-6: The distribution of ATSPs based on ownership (inner circle equals employment; outer circle equals the number of organisations).

2.4 State of implementation of ATCO fatigue-related requirements

The study concluded that the applicable EU requirements on ATCO fatigue have been well implemented throughout the EU Member States by 2023. This is confirmed by the findings from the EASA standardisation inspections in the period 2020 – 2022 that covered the ATCO fatigue regulatory requirements. There were 10 non-compliances regarding Regulation (EU) 2017/373 distributed over seven ATSPs. For one ATSP, four non-compliances were identified, and for the other six ATSPs, one non-compliance was identified. Between 2017 and 2023, there were seven non-compliances regarding Regulation (EU) 2015/340. According to EASA, these non-conformities were all resolved by 2023.

By 2023 the applicable EU requirements on ATCO fatigue have been generally well implemented throughout the EU Member States and no significant difficulties were observed in their implementation. Compared to the situation before the adoption of the ATCO fatigue provisions, the analysis of available data indicated that the situation has positively evolved between 2017 and 2023. In 2023:

- 100% of the ATSPs have implemented an ATCO fatigue management policy.
- 88% of the ATSPs have a dedicated fatigue reporting mechanism, while 12% of the ATSPs report through the standard occurrence reporting system under Regulation (EU) 376/2014.
- 100% of the ATSPs declare that they assess fatigue as a potential contributing factor in occurrence investigations and analysis.
- 100% of the ATSPs have procedures in place for the identification and management of the effect of fatigue on operations safety, with 40% of the ATSPs collecting sleep or fatigue data on a quarterly or yearly basis.

- 88% of the ATSPs have included a specific module on fatigue in ATCO training, while 12% of the ATSPs are meeting this requirement only partially.
- 100% of the ATSPs have an information programme for ATCOs on the prevention and effect of fatigue.

While the requirements appeared to be fulfilled, the ATCO associations stressed that these measures are often either insufficient or ineffective in practice.

Regarding the rostering systems, there are differences between the values applied by the ATSPs for the eight roster elements defined in Regulation 2017/373. Table 2-1 shows the average maximum and minimum values, with standard deviation, for the roster elements based on the data collected from the 36 ATSPs. The table shows the data on the eight roster elements differentiated between ATS provided from an ACC and an aerodrome for 2023.

Table 2-1: Average maximum or minimum values and standard deviations for the eight roster elements differentiated between ATS provided from an ACC and from an aerodrome for 2023.

Roster element	Area Control Centre (ACC)		Aerodrome (TWR)	
	Average	Standard deviation	Average	Standard deviation
(1) maximum consecutive working days with duty (days)	5.9	1.4	5.8	1.7
(2) maximum hours per duty period (hours)	9.2	3.0	10.5	2.7
(3) maximum time providing air traffic control service without breaks (minutes)	90	38	154	89
(4) ratio of duty periods to breaks when providing air traffic control service	0.69	0.10	0.72	0.10
(5) minimum duration of rest periods (hours)	11.6	5.3	12.0	5.1
(6) maximum consecutive duty periods encroaching the night-time (days)	2.3	1.0	2.9	1.2
(7) minimum rest period after a duty period encroaching the night-time (hours)	22.5	19.5	17.8	15.5
(8) minimum number of rest periods within a roster cycle	3.7	2.0	3.7	4.5

Overall, the results show a potential improvement on the average values of several roster elements in 2023 compared to 2017. For ATSPs providing services at ACCs, the changes between 2017 and 2023 led to a potential improvement of the ATCO working conditions for four elements of the rostering system and to a potential deterioration of the ATCO working condition for one element of the roster. For ATSPs providing services at aerodromes only, the changes between 2017 and 2023 led to a potential improvement of the ATCO working conditions for three elements of the rostering system and to a potential deterioration of the ATCO working condition for four elements of the roster. The details are provided in Annex D

The results show a variation and broad range of applied values for all roster elements. In general, the variation for ATCOs working at ACCs is less than the variation for ATCOs working at aerodromes. The study shows that there are differences between the average values used by the ATSPs providing services at ACCs and the average values used by ATSPs providing services at aerodromes only. Between 2017 and 2023, the differences in the average values of the following elements of the rostering system have increased:

- The maximum hours per duty period;
- The maximum time providing services without breaks;
- The maximum consecutive duty periods encroaching the night time; and
- The minimum rest period after a duty period encroaching the night time.

Between 2017 and 2023, the differences in the average values of the following elements of the rostering system have decreased:

- The minimum duration of rest periods; and
- The minimum number of rest periods within a roster cycle.

To summarise, the results on the eight mandatory roster elements show the following trends:

- The average maximum time providing air traffic control service without breaks has slightly decreased since 2017 for ATCOs at ACCs;
- There is a difference in average maximum time providing air traffic control service without breaks between ATCOs at ACCs and those at TWR, with the later having slightly longer working hours. This difference may be explained by the nature of the tasks or operational conditions, but this was not further analysed as part of this study.
- There are large variations in some of the roster elements, notably the maximum hours per duty period, the minimum duration of rest periods and minimum rest period after a duty period encroaching the night time[10].

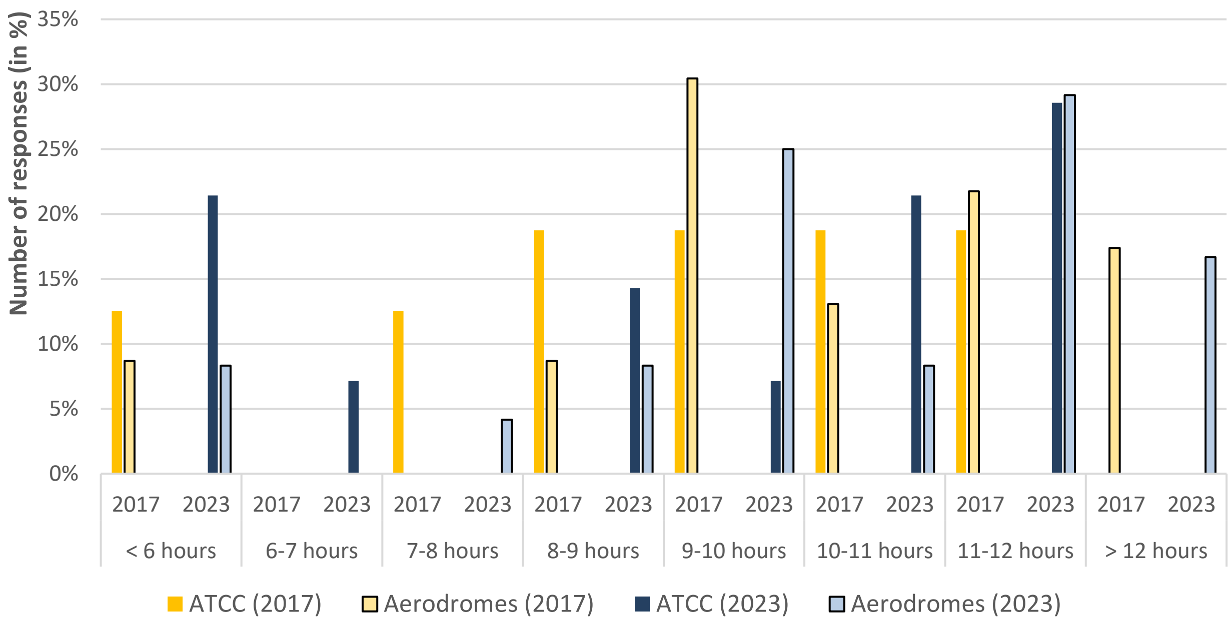
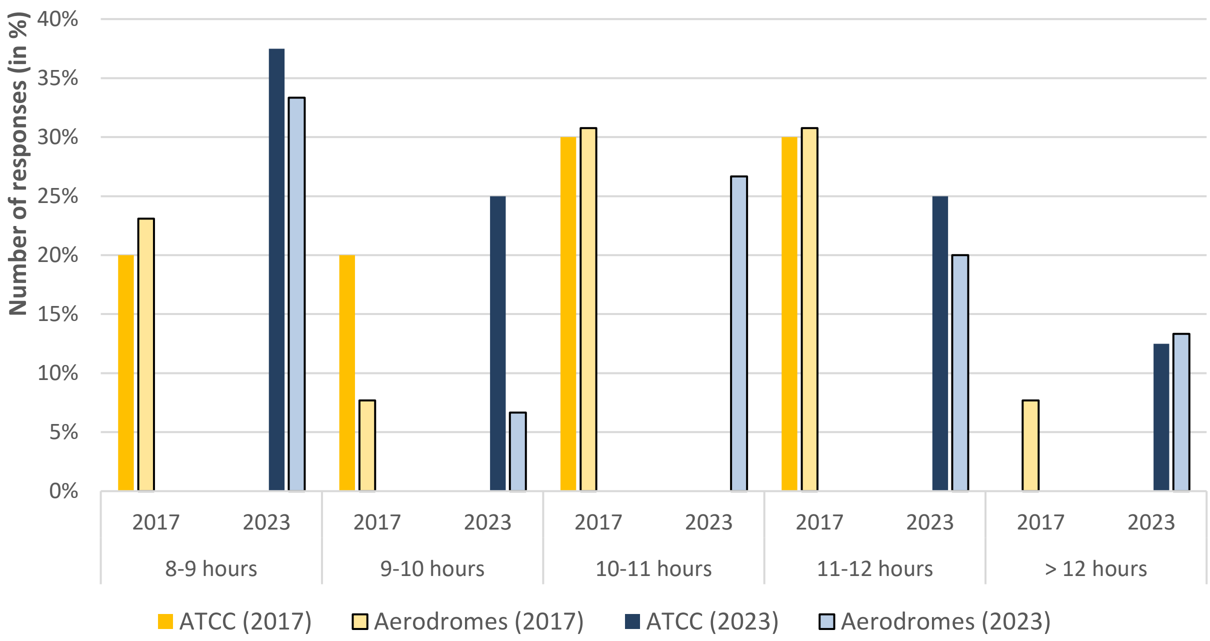


Figure 2-7: ATSP survey results on "Maximum hours per duty period" prior (situation 2017) and since (situation 2023) the adoption of Regulation (EU) 2017/373.



[10] Data related to the other five mandatory roster elements can be found in study deliverable D-1.A.2 & D-1.B.

Figure 2-8: ATSP survey results on "Minimum duration of the rest period" prior (situation 2017) and since (situation 2023) the adoption of Regulation (EU) 2017/373.

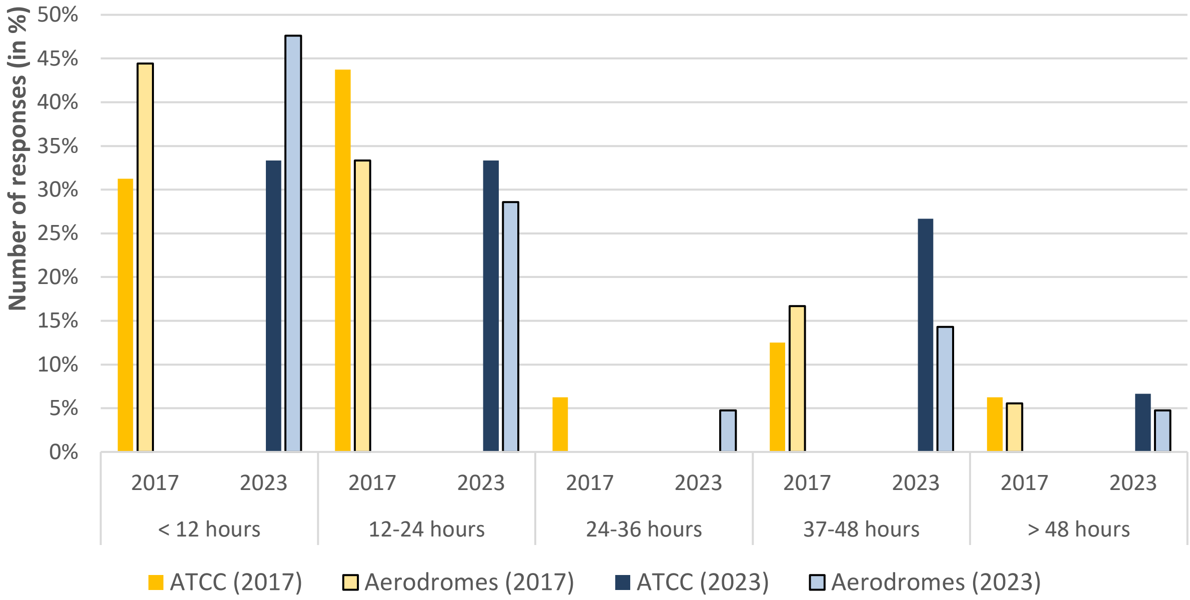


Figure 2-9: ATSP survey results on "Minimum rest period after a duty period encroaching night time" prior (situation 2017) and since (situation 2023) the adoption of Regulation (EU) 2017/373.

This lack of level-playing field can be explained by local conditions which differ from one country and from one ATSP from another. Flexibility needs, ATCOs personal factors, specific national requirements (labour law) and traffic volumes are the main factors influencing the rostering (see Figure 2-10).

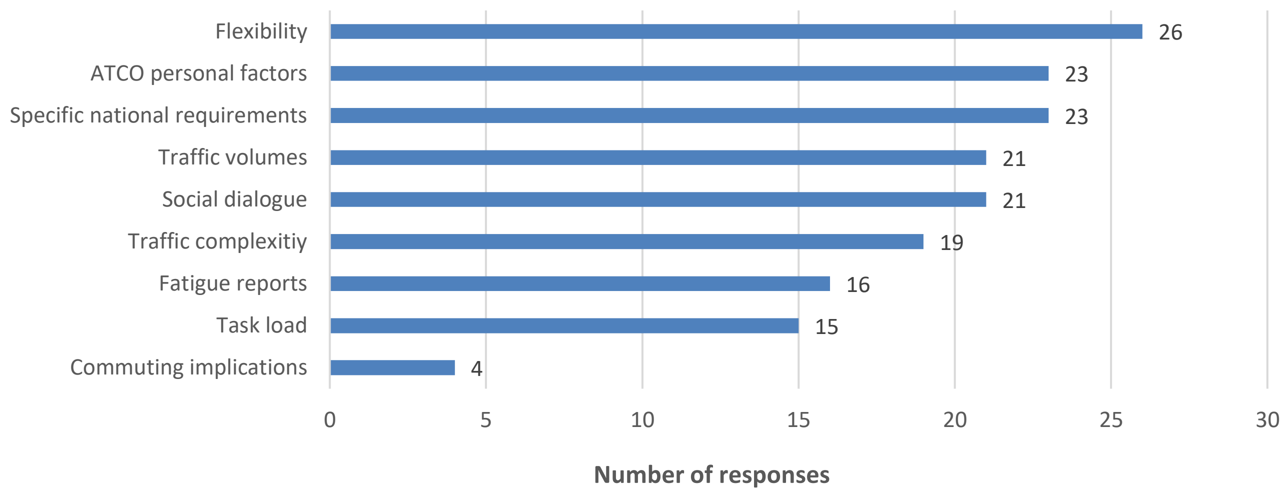


Figure 2-10: Summary of the ATSP responses to the question "What other dominant factors have been taken into account in the development and management of your organisation's rostering system?"

Study results show that deviations from the planned roster regularly happen at the initiative of the ATSP, to take into account specific or unforeseen operational situation. Other changes, initiated by the ATCOs, e.g. swapping shifts, are sometimes made without systematic monitoring by the ATSPs. Some ATSPs however allow changes to the rosters after publication, only through a software that automatically checks that the rostering standards are still adhered to. Deviations from the planned roster may require attention from the competent authorities.

2.5 Assessment of impact of the ATCO fatigue regulatory requirements

The impact of the implementation of the ATCO fatigue regulatory requirements has been assessed based on the collected data in terms of effectiveness, efficiency and added value[11] in line with the EU Better Regulation methodology. Data was collected from the survey with the 36 ATSPs, 18 interviews with a representative sample of ATSPs, written responses to open questions provided by ATCO associations, a survey with NSAs/NAAs, and desktop research.

2.5.1 Effectiveness

Effectiveness considers to what extent the objective of the ATCO fatigue regulatory requirements has been met[12]. The objective of the ATCO fatigue regulatory requirements is "to prevent and mitigate the negative effects of fatigue on air traffic controllers to ensure the safety of air traffic", as stated in ATS.OR.300. The ATCO fatigue regulatory requirements have resulted in a slight increase in the annual number of reported ATCO fatigue-related occurrences. However, this conclusion should be treated with caution because there are concerns about the quality and completeness of the data, as explained in section 4.2. Moreover, there are indications that the fatigue reporting mechanisms are not fully effective (see also section 4.3.3).

The ATCO fatigue regulatory requirements have raised awareness of fatigue in general and reporting of ATCO fatigue in particular. Additionally, the ATCO fatigue regulatory requirements have increased the predictability and transparency of the roster development process. This improved the motivation of the employees and allowed a better understanding of the process by the ATCO representatives and unions, thus resulting in more effective coordination. Implementing the ATCO fatigue regulatory requirements was achieved without any strong social resistance and generally did not affect the lifestyle or well-being of ATCOs. There are indications that the existing information programmes on fatigue are not always considered to be useful.

While ATCO fatigue is considered as an organisational concern, the current implementation of the fatigue management requirements generally helped improve the situation.

2.5.2 Efficiency

Efficiency considers the proportionality of the benefits and costs arising from the ATCO fatigue regulatory requirements. In order to do so, the safety, economic and social effects are quantified in terms of costs and benefits.

The implementation of the ATCO fatigue regulatory requirements since 2017 had a small economic impact. Total implementation costs for the ATSPs in the 2020 – 2022[13] period were estimated at € 16 million. It was estimated that 30 additional ATCOs were recruited overall in the EASA Member States to comply with the ATCO fatigue regulatory requirements. This corresponds to an increase of 0.2% in the number of ATCOs in the EASA Member States. For the NSAs/NAAs, the economic impact of the ATCO fatigue regulatory requirements was considered to be negligible. The effect of ATCO fatigue regulatory requirements on the number of ATCO fatigue-related occurrences cannot be determined due to the limitations in the ECR data for ATCO fatigue occurrences, as detailed in Chapter 4. Therefore, the costs of the ATCO fatigue regulatory requirements could not be compared with the safety benefits. Consequently, the efficiency of the ATCO fatigue regulatory requirements could not be further quantified.

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[11] See for substantiation of the conclusions in this section the study deliverables D-1.A.2 & D-1.B.

[12] See Better Regulation Guidelines and Toolbox (EC, 2023).

[13] The costs were incurred by ATSPs in this limited time period according to the ATSP survey and interview results; accordingly, for the economic impact analysis this period was applied.

2.5.3 Added value

The added value concerns the changes resulting from the ATCO fatigue regulatory requirements, over and above what could reasonably have been expected from national actions by the EASA Member States. The ATCO fatigue regulatory requirements helped to achieve a more homogenous framework for the prevention and mitigation of ATCO fatigue. However, because the values of the roster elements are determined by national regulations, and local conditions and practices, the requirements did not result in a complete level playing field across the EASA Member States.

2.5.4 Opportunity for improvement

The present study found that 73% of the responding ATSPs, 60% of the responding NSAs and 28% of the responding ATCO associations believe that the current ATCO fatigue regulatory requirements are sufficient and do not require further improvements. While it can be concluded that the EU ATCO fatigue regulatory requirements have been overall effective, efficient and have added value, a number of specific challenges and issues have been identified.

Indeed, several ATSPs, ATCO associations and NSAs/NAAs indicated that they look for more guidance on:

- More precise definitions or guidance on some terms and definitions which are not equally understood and applied across ATSPs.
- The fatigue reporting mechanisms.
- Specifications and guidance on how certain mandatory elements of the regulations should be implemented (including measures for the identification and management of the effects of fatigue and the information programmes on fatigue).
- Reference values for rosters and working practices.

From the study, it appeared that there are qualitative differences in the way that the ATSPs have implemented the ATCO fatigue regulatory requirements. The study observed variance across ATSPs in EU in the eight roster elements and the maximum and minimum values applied by ATSPs as a result of national regulations and local practices. Therefore, guidance to achieve a better level-playing field on work and rostering practices could be considered for the future.

3. Review of current level of knowledge on ATCO fatigue

3.1 Introduction

As part of the study, an extensive literature review was performed to assess the existing scientific knowledge regarding the prevalence, causes, impact and mitigation of ATCO fatigue. The results were compared with scientific literature from other comparable or relevant professional domains involving safety-critical tasks and irregular working hours, and knowledge gaps were identified.

The research team compiled an overview of the existing peer-reviewed literature by conducting a literature search in scientific databases (see details in Annex C). In addition to the systematic literature search on peer-reviewed articles, experts from within the consortium and EASA network were asked to provide additional 'grey' literature. Grey literature is research material by organisations outside the traditional commercial or academic publishing and distribution channels. It can include, amongst others, theses, dissertations, research and committee reports, government reports, conference papers, and ongoing research.

The collected information was systemically assessed and summarised using data extraction from the literature and synthesising the studies' findings. To determine the current level of knowledge regarding the causes of ATCO occupational fatigue, its impact on alertness and performance, and the relationship with safety risks, only data from studies that were rated as being 'good' or 'fair' was extracted.

Next, the researchers composed a list of issues/aspects that appeared to be missing or not sufficiently covered in the existing fatigue-related literature about ATCOs, in comparison with the other relevant domains, such as:

- Aircrew members (restricted to crew members exposed to short- or medium-haul flights, who therefore experience a minimal number of time zone crossings during their duties);
- Operators working in shift schedules (day, evening and night shifts; on-call duties) from various domains (e.g. healthcare workers, train drivers and railway traffic controllers, operators at nuclear power plants and oil rigs) who have safety-critical tasks, and/or operate in a control room like setting.

In the gap analysis, both EASA and consortium experts identified the most relevant gaps in the context of the objectives of the present research study.

The outcomes of the ATCO-specific literature review (based on both peer-reviewed and grey literature) are described in section 3.2.1. The outcome of the review on information available in other relevant domains is also described. The results of the gap analysis are presented in section 3.2.2. More information on the approach to the literature review is provided in Annex C [14].

3.2 Results

3.2.1 Results from the literature review

From the selection of ATCO fatigue peer-reviewed articles that were retrieved, 15 articles of good quality were analysed. In addition, six reports of acceptable quality were added, based on the grey literature collection and selection procedure, leading to a total of 21 papers for the data extraction and analysis.

[14] For further information on the approach and details of the literature review refer to study deliverables D-2.A.1, D-2.A.2, D-2.A.3.

Based on the analysis of the existing literature, the following results were found:

1. The scientific literature on ATCO fatigue in the EU is very limited

A total of 21 scientific reports and articles on ATCO fatigue of acceptable quality since the year 2000 were found. The literature review also found that the implementation of the Commission Implementing Regulation (EU) 2017/373 has yet to lead to more publicly available knowledge regarding the prevalence of fatigue.

The fact that the majority of the 21 studies were conducted outside of the EU leads to the assumption that the findings are not necessarily generalisable to the European situation since laws and regulations, work practices, hours, and schedules outside the EU can differ substantially from those in Europe. Work practices and work environment differ between countries/continents and can translate into different levels of task complexity, workload, and subsequent fatigue (Nealley & Gawron, 2015). Furthermore, most studies included a relatively small number of participants, and the representativeness of these participants compared to the non-participants was not presented. Two articles that were analysed concerned cross-sectional survey studies with about 200 participants. However, when interpreting the validity of the results of these studies, it should be considered that surveys and self-report studies are vulnerable to several biases, such as selection bias, response bias, question bias, and confirmation bias.

2. Average fatigue levels during shifts were found to be moderate, although a majority of ATCOs indicate to experience critically high fatigue on an occasional level

Moderate levels of fatigue during shifts were found in observational studies from Asia and the U.S. From retrospective cross-sectional studies, it became clear that 50-75% of the ATCOs indicated that during the past year, it had occurred that they dozed off and felt tired and weary during and after work. Therefore, although average fatigue levels found during shifts can be moderate, critically high fatigue levels can, at some point, occur as well.

3. Most scientific evidence regarding causes of ATCO fatigue reflects work-related factors

Considerable knowledge proved to be available for the causes of ATCO fatigue. These causes can be divided into two categories: work-related and non-work related. The majority of the evidence concerns work-related factors, and more specifically, work-schedule and workload-related factors. Work-schedule characteristics associated with fatigue are quick turnarounds, counter clockwise rotations, (number of) night shifts, and a high number of consecutive shifts. Less evidence is available for the non-work related factors such as sleep disorders, work-home balance, and individual characteristics.

4. There is a lack of scientific evidence about the effects of fatigue in ATCOs

A limited number of articles were found about the effects of fatigue in ATCOs. It was concluded that there is not enough evidence from incident data analysis to determine an association between ATCO fatigue and errors or incidents. Some observational and retrospective studies found that ATCO fatigue can lead to decreased performance and situational awareness.

5. Napping during breaks and optimal shift scheduling has been shown to mitigate fatigue

From the literature about fatigue mitigation, it could be derived that napping during breaks can lead to increased performance and reduced fatigue in ATCOs during night shifts. In addition, studies that looked at optimal shift scheduling found a positive effect of increased rest periods, shorter duties, and schedules that fit the preferences of the working population.

6. Literature on ATCO fatigue is not as extensive as literature on fatigue in aircrew

Compared with the other relevant domains, the number of peer-reviewed articles on ATCO fatigue is somewhat limited, especially in comparison with literature on aircrew, where much more peer-reviewed research is available. However, compared to the other safety critical domains investigated, the number of studies about ATCO fatigue resembled those available from the rail domain, and exceeded the number of articles found for both the healthcare and energy domain.

Based on the review of key literature from the other safety critical domains, significant gaps were identified in the current – ATCO specific – scientific knowledge on fatigue prevalence, effects, and possible mitigations. This was specifically noted when compared to the literature about (short/medium-haul) aircrew. However, for the causes of ATCO fatigue, it was shown that considerable knowledge on both work- and non-work related factors is already available, compared with other relevant domains such as healthcare, energy, and rail. Based on the analysis of the relevant literature, Table D-1 in Annex D.1 compares the main findings of the ATCO literature with the literature from other domains.

3.2.2 Results from the gap analysis

The main knowledge gaps between the domains, as derived from the available scientific literature, are shown in Annex D.1 (Table D-2). Most of these gaps were therefore included or covered as part of the research activities in the present ATCO fatigue research study:

- For the data collection campaign, the consortium selected and included a representative sample of European ATSPs and ATCOs, ensuring that a diverse set of commonly used European-specific work schedules were included in the study.
- The data collection campaign included questions on perceived workload during the shifts. Findings from both the energy and rail sectors have already shown the significant fatiguing effect of boredom, inactivity and increased automation, which could also apply to ATCOs.
- Non-work related factors such as age, gender, experience, work-family balance, fitness, and general health were included in the baseline questionnaire the participants completed. These variables were taken into account during the analysis of the data.
- Real-time, objective measurements were performed as part of the data collection campaign in the current study, assessing fatigue, cognitive workload and performance in a subsample of ATCOs during shifts that had been identified as fatigue hotspots.
- Existing and applicable knowledge from more generic shift worker research and specific domains regarding work patterns, duty lengths, breaks within duties and rest periods was used as a starting point for developing recommendations on the management of ATCO fatigue risk in the operational environment (see Chapter 6). The existing knowledge on approaches to prevent and mitigate ATCO fatigue as well as the findings from the review of the current evidence based knowledge in the other relevant domains were taken into account in the development of practical means (outside roster design) for the prevention and mitigation of ATCO fatigue.

4. Review of ATCO fatigue-related occurrences

4.1 Introduction

The study collected and analysed a set of data on ATCO fatigue-related occurrences covering the last ten years (2013 - 2022) in the EASA Member States, including the United Kingdom (UK) until 2020, to provide anonymised statistics and analysis on aviation safety occurrences caused by ATCO fatigue in the EASA region. Note that the EASA Member States cover the 27 Member States of the EU plus four non-EU States, including Iceland, Liechtenstein, Norway and Switzerland. The UK was a Member State of EASA and the EU until 2020 and is considered as the 32nd EASA Member State until 2020 in this report.

The data was queried from two data sources: the European Central Repository (ECR) and the NLR Air Safety Database. EASA performed the ECR query, and the anonymised results were made available for the present study exclusively. In addition, NLR used the NLR Air Safety Database to obtain accident and serious incident cases in which ATCO fatigue played a role. It is important to mention that ATSPs communicated no additional safety occurrences to the research team in response to the survey amongst the 46 ATSPs in the EASA Member States. After a set of relevant data was generated through the review process, a selection of relevance and a provision of categorisation, and a statistical analysis of different variables was performed. The main findings are summarised in the next section, followed by a discussion on the quality and completeness of the data in section 4.3. More information on the data sources and approach is provided in Annex C . For further information on the approach and details of the data analysis, see the study deliverable D-2.B.

4.2 Results

ATCO fatigue is rarely reported or identified as the cause or a contributing factor of accidents.
This is shown by the data derived from the NLR Air Safety Database which contains primarily serious incidents and accidents. Considering only 2013-2022 and the region of the EASA Member States and the UK (UK included until 2020), no ATCO fatigue-related accidents or serious incidents have been reported. The number of relevant ATCO fatigue-related accidents or serious incidents found worldwide in the NLR Air Safety Database is very small: only five relevant cases are found from 2001-present[15], all concerning non-EU States.

Data collected from the ECR shows that only a small number of incidents related to ATCO fatigue occurred in the analysed time period.
This indicates that the likelihood of ATCO fatigue-related occurrences is low. Based on the analysis of the ECR and the NLR Air Safety Database data sets, several findings and observations are made:

- A total of 184 occurrences were found where ATCO fatigue was mentioned. These occurrences were not classified as an accident or serious incident. Out of these 184, the number of occurrences with a (potential) unsafe outcome, obtained from the ECR, is 59. The number of occurrences without a (potential) unsafe outcome, i.e. consisting of mere fatigue reports, is 125 (see Figure 4-1).
- The 59 cases with a (potential) unsafe outcome were reported by eight (out of 32) EASA Member States and 37% of these cases were reported by a single Member State.
- The 125 cases with no (potential) unsafe outcome were reported by eight (out of 32) EASA Member States and 68% of the reports came from a single Member State.
- It is striking that ATCO fatigue was reported more often by certain ATSPs and for a certain but limited time period.

[15] Initially NLR chose a longer period for data search such that as much as possible data can be collected for analysis.

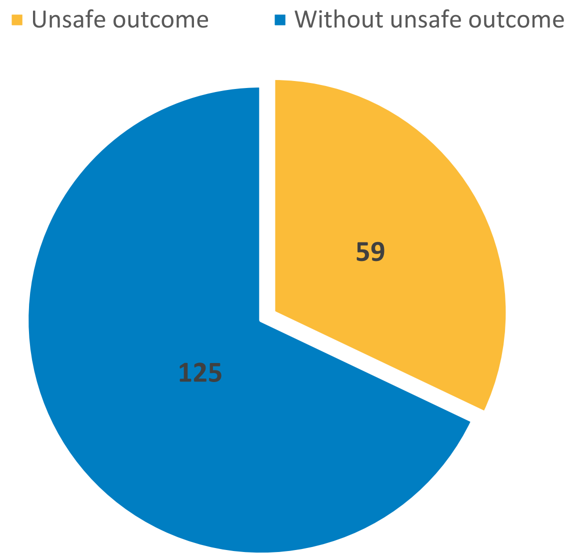


Figure 4-1: Distribution of ECR data sample of occurrence reports with an unsafe outcome (59) and without an unsafe outcome (125) in the period 2013-2022 in the ECR database.

The analysis of the available data on ATCO fatigue-related occurrences shows the following results:

- The contributing factors mentioned most often in the description of ATCO fatigue-related occurrences were work schedule, excessive workload and lack of rest.
- No correlation was found between the time of the day and the number of ATCO fatigue-related occurrences per flight.
- Most ATCO fatigue-related occurrences took place during the en-route flight phase.
- The three types of unsafe outcomes were mentioned most in the description of ATCO fatigue-related occurrences: loss of separation, airprox, and wrong instruction given.

In total, 59 occurrences with a (potentially) unsafe outcome were identified between 2013-2022 related to ATCO fatigue. 25 of these events occurred between 2013-2017, and 34 occurred in 2018-2022. The ECR also contains 125 ATCO fatigue-related occurrences without a potentially unsafe outcome between 2015-2022. Six events occurred during 2015-2017 and 119 during 2018-2022. Figure 4-2 and Figure 4-3 show the number of occurrences per year for, respectively, the occurrences with a potential unsafe outcome, and without potential outcome. Note that the number of flights in the EASA Member States were significantly reduced in 2020 and 2021 due to the COVID-19 pandemic.

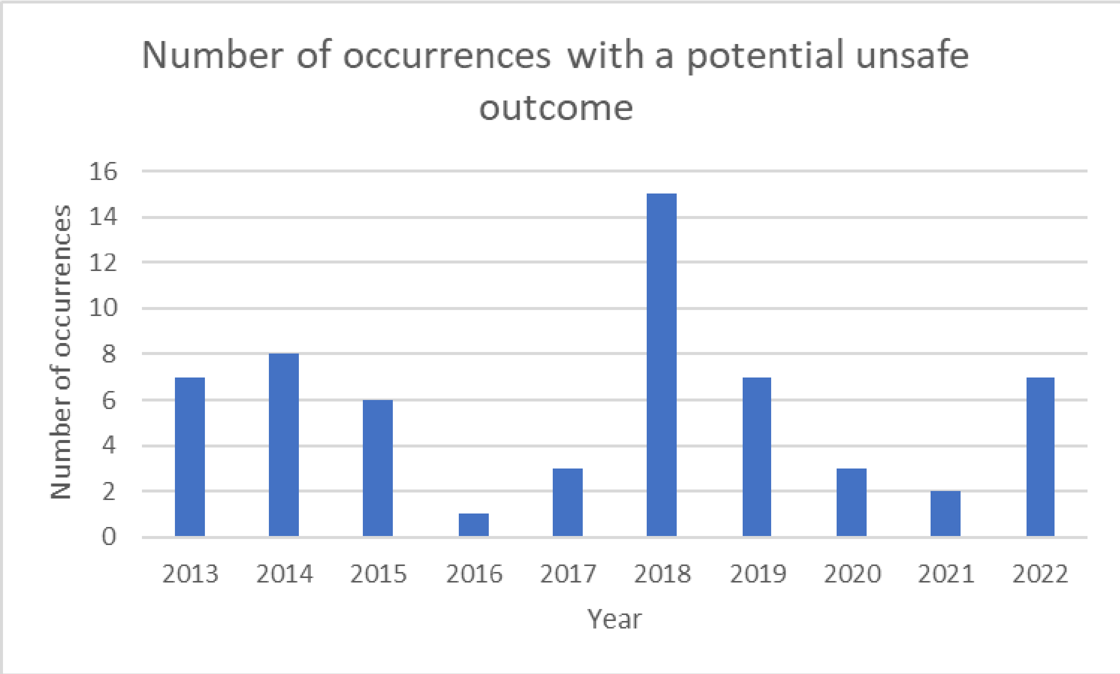


Figure 4-2: Annual number of occurrences with (potential) unsafe outcome in the period 2013-2022 in the ECR database.

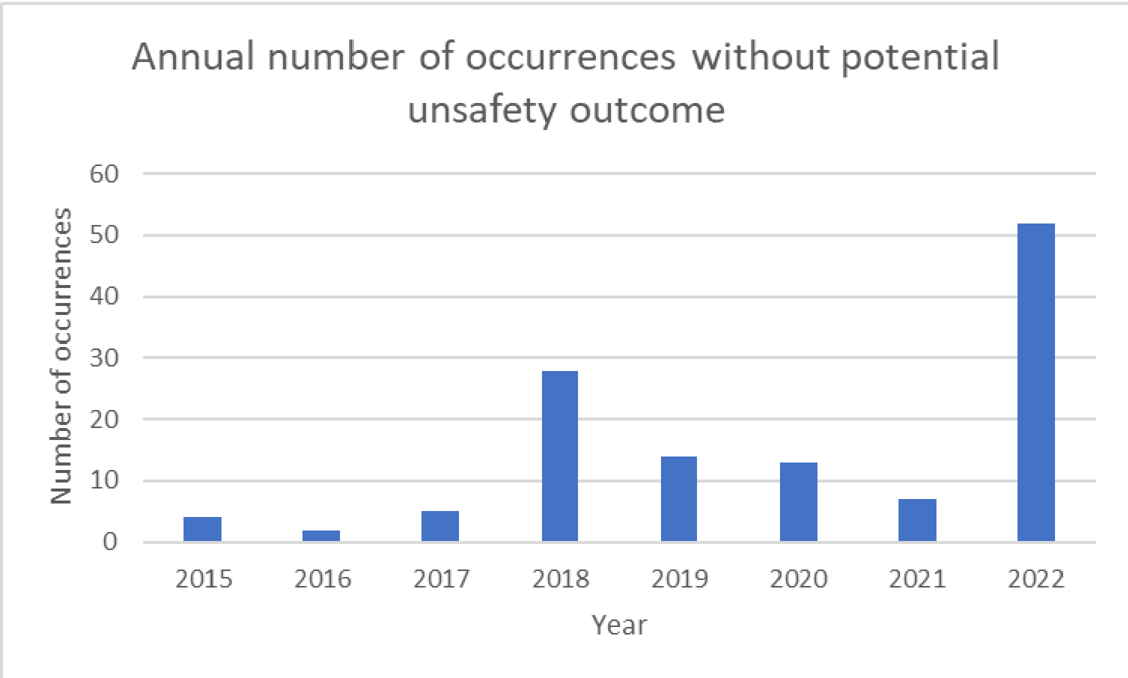


Figure 4-3: Annual number of occurrences without potential unsafe outcome in the period 2015-2022 in the ECR database.

4.3 Caveats on results of the ATCO fatigue-related occurrence reporting

This section discusses the data quality, completeness and reporting bias, the volume of ATCO fatigue-related occurrence reports, and compares the outcomes with results from literature.

4.3.1 Data quality, completeness and reporting bias

In general, the ECR is a versatile occurrence reporting system. It includes a vast amount of aviation occurrence data covering all the EASA Member States including the UK up until 2020. However, when the focus is put on the sample of ATCO fatigue-related occurrences, three ECR deficiencies are observed.

Firstly, the data lacks good quality of reporting and completeness. In several reports, basic information like the 'phase of flight' or 'time of the occurrence' was missing.
Secondly, the level of detail provided in the vast majority of reports was insufficient to conduct a full human factors analysis using a comprehensive taxonomy, which could, for instance, relate the event to e.g. a work schedule and previous duty times of the ATCO involved in the occurrence. Additionally, some reports are truncated at different levels, though still complying with the minimum reporting requirements. This is typically reflected by short narratives that provide limited information regarding the occurrence without clear details on the circumstances or causes. In other cases, only preliminary reports are in the ECR, which have not yet been updated with a detailed investigation. Preliminary reports often do not provide complete information on the causal or contributing factors (e.g., about why the occurrence happened) and only give a basic summary of the occurrence in the narrative of the reports (e.g., about what has happened), which might even be incomplete or incorrect. As a result, the data sample available in this study provides some insight into the causal and contextual factors in ATCO fatigue-related occurrences and unsafe outcomes related to ATCO fatigue. However, there is insufficient detailed information in the data collected and analysed to elicit the relationship between ATCO fatigue-related occurrences and fatigue risk management practices.
Thirdly, biases in reporting are found. The results show that the reported occurrences originate from only eight out of the 32 EASA Member States (incl. UK), with 68% originating from one Member State. Also, there is a discrepancy between the number of reported occurrences known to the ATSPs (from the survey results) and the number of occurrences in the ECR database. For instance, one ATSP indicated in the survey that it experienced a large increase in reports, suggesting that the number of ATCO fatigue reports and fatigue-related occurrences increased from 64 in 2021 to 419 in 2022. This number is larger than the number of ATCO fatigue-related occurrences found in the data sample from the ECR database. This suggests that not all occurrence reports end up in the ECR database.

In conclusion, the analysis of the reported occurrences in the ECR database yielded concerns about the representativeness of the data. For the present study, the issues described above limited the detailed (statistical) analyses and affected the usability and statistical validity of the results. It cannot be ascertained that the results are representative for all EASA Member States.

4.3.2 Volume of ATCO fatigue-related occurrence reports

ATCO fatigue regulatory requirements have resulted in a small increase in the annual number of reported occurrences. However, there are indications that the fatigue reporting mechanisms are not fully effective. The obligation to report on fatigue became mandatory only as of January 2020 as part of Regulation 2017/373[16]. In total, 24 of the 31 ATSPs (77%) responding to this topic in the survey indicated that the implementation of the ATCO fatigue requirements did not affect the number of reported occurrences related to ATCO fatigue. Six ATSP survey respondents (19%) indicated that the number of occurrence reports related to ATCO fatigue has increased (two ATSPs indicated a large increase). In contrast, one ATSP (3%) indicated that the number of occurrence reports decreased.

According to 80% of the responding NSAs to the survey, there was no effect on the number of fatigue-related occurrences reported to the NSA following the implementation of the ATCO fatigue regulatory requirements.

[16] See AMC1 ATS.OR.315(a) Fatigue Management Policy.

One respondent (10%) observed a large increase of fatigue-related occurrences. According to this respondent, the increase was due to the gradual recovery of the air traffic levels after the COVID-19 pandemic, the sensitivity of organisations to fatigue-related issues, and the significant increase in the reporting culture. The respondent also indicated that fatigue-related occurrences could be mixed or confused with labour-related issues.

The implementation of dedicated fatigue reporting mechanisms did not seem to have an effect on the number of reported occurrences either. The data presented in the ECR database, in combination with the ATSP responses in the survey, suggest a small increase in the annual number of reported occurrences. However, this conclusion should be treated with caution because there are concerns about the quality and completeness of the ECR data, as explained above. Some ATCO associations expressed concerns about the lack of effectiveness of the fatigue reporting mechanisms which could be a reason for the low number of reports. This aspect may need to be further investigated. The ATCO fatigue regulatory requirements may have resulted in a raised awareness of fatigue in general and on reporting of ATCO fatigue in particular.

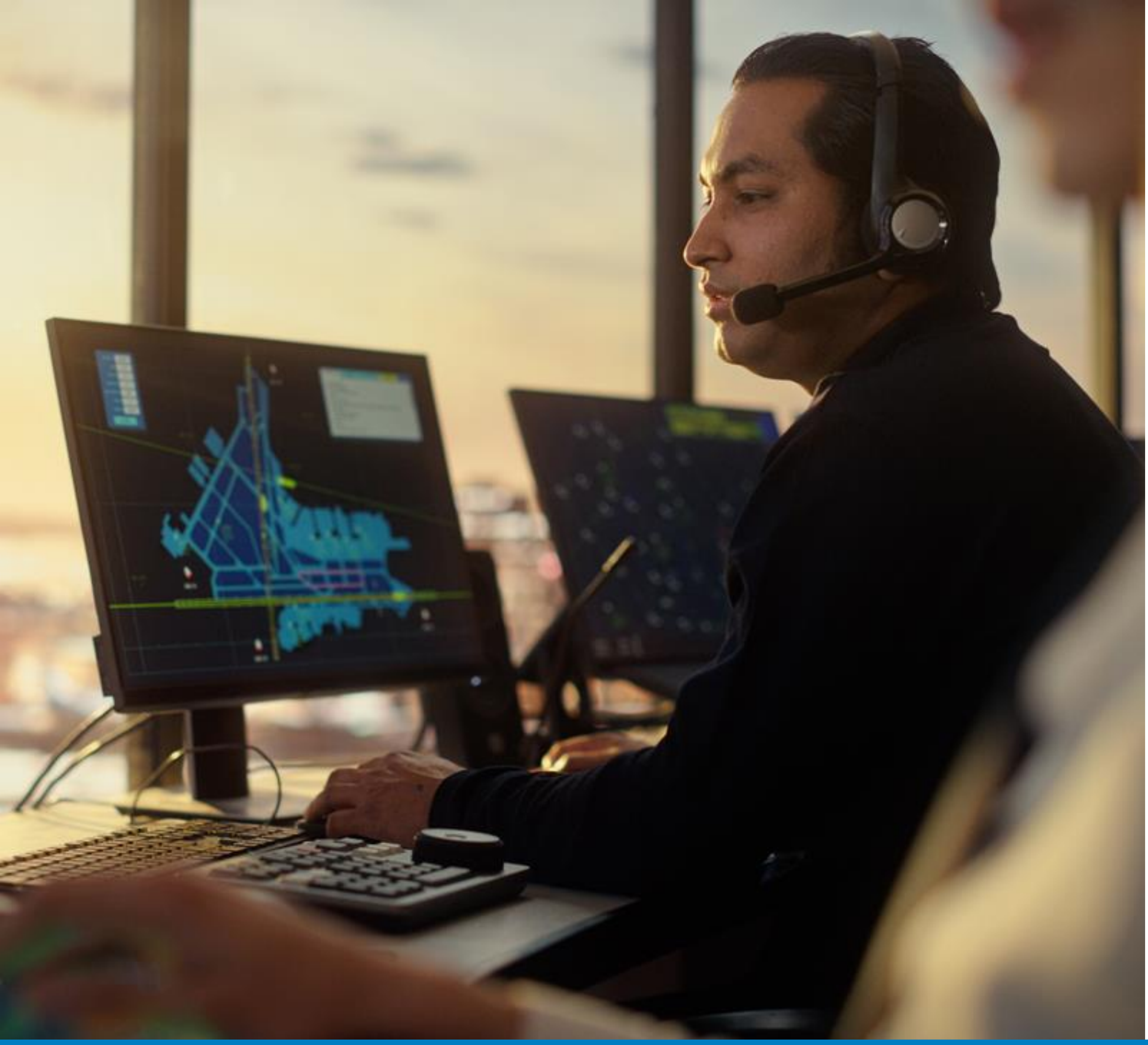
Through discussions with stakeholders in the course of the study, it was recognised that the small number of reports on ATCO fatigue and fatigue-related occurrences may be partly because systems were only recently implemented to collect, analyse and report these types of data. In addition, it was recognised in the discussions with social partners that there is no specific place in the occurrence report forms provided by the authorities to indicate fatigue. This might explain why the number of reports on fatigue was so low. Furthermore, ATCOs are not sufficiently trained on the identification of fatigue, and therefore, may not report fatigue, according to the social partners. It is remarked that the present data analysis cannot verify these statements.

4.3.3 Comparison with results from the literature review

The results found by the data analysis are in line with findings from the literature review. A limited number of peer-reviewed articles were found in the literature review about the effects of fatigue in ATCOs. While older incident data showed an association of ATCO fatigue levels with errors or incidents (Gander, 2001), this could not be replicated in the past 23 years. Nealley & Gawron (2015) concluded that there was not enough (high-quality) data available, and Li et al. (2021) could not find an association based on the Eurocontrol incident database.

From the grey literature search, Orasanu et al. (2012) reported that controllers thought fatigue played a substantial part in their ability to effectively perform tasks, and work-related safety occurrences.

To conclude, there is not enough data to show an association between ATCO fatigue and errors or incidents.



Part II: ATCO Fatigue Prevalence, Causes and Effects in Actual Operations

5. ATCO fatigue prevalence, causes and effects in actual operations

5.1 Approach

This section presents the scientific research approach applied for the assessment of the prevalence and level of ATCO fatigue, as well as the contributing factors and effects. Three research activities were conducted in a step-wise approach to conduct the data collection (see Figure 5-1). For more information on the approach, methodology, analysis and results, refer to the study deliverable D-2.C.2.

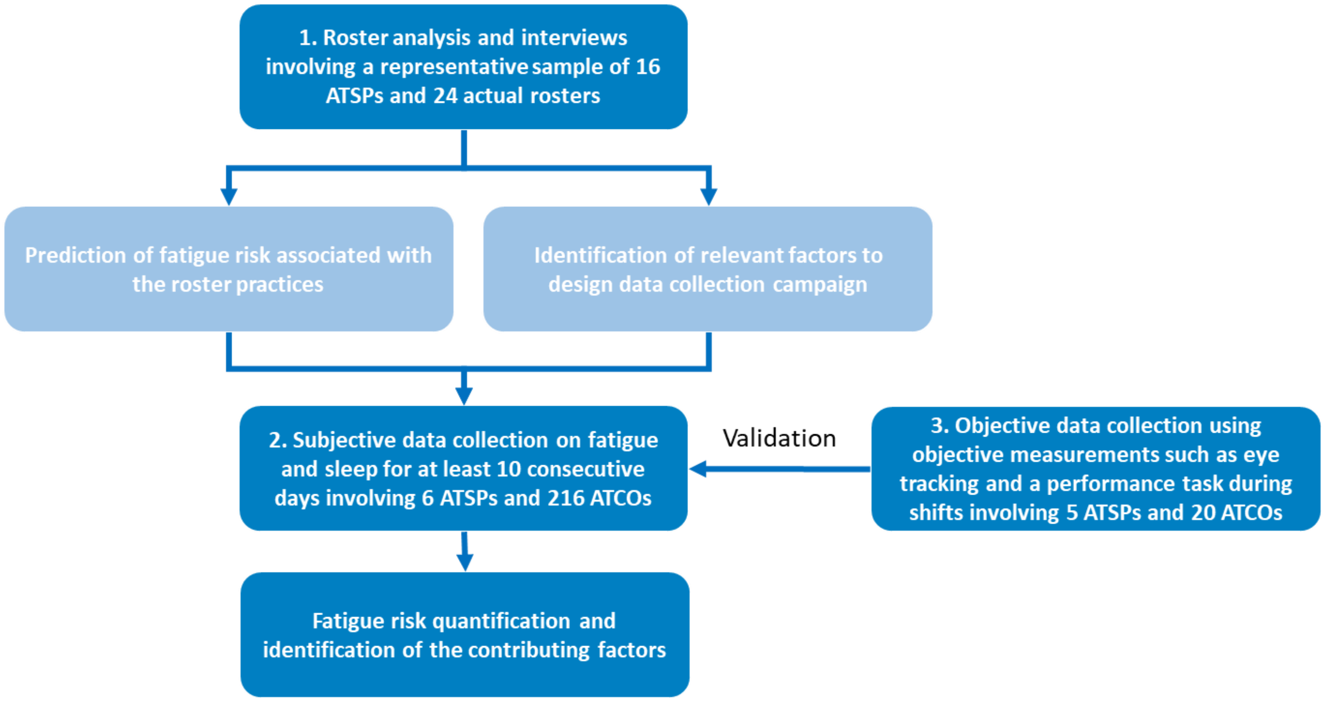


Figure 5-1: Overview of three main data collection activities for the collection of scientific data on ATCO fatigue in the present study.

Step 1: Roster analysis
A representative sample of 16 EU ATSPs was selected to conduct an analysis of their actual ATCO rosters. The representativeness criteria included:

- traffic volume (en-route and aerodrome movements),
- the geographical location,
- the ATCO-hour productivity,
- legal status and ownership.

The objective of the roster analysis was to identify and assess the level of exposure to fatigue in actual ATCO rosters. Interviews were conducted with this representative sample of ATSPs to obtain detailed insights into the rostering system and fatigue management practices within the ATSPs[17]. Additionally, a sample of 24 actual rosters from the 16 ATSPs was analysed for exposure to fatigue. The participation of ATSPs in the interviews and roster analysis took place on a voluntary basis.

[17] These interviews were separate from the interviews conducted under Task 1 in this study, which aimed at assessing the effectiveness of the implementation of the EU ATCO fatigue regulatory requirements in general. The interviews referred to in this section focussed on details of the rostering system and fatigue management practices within the 16 ATSPs.

Each of the 16 ATSPs were invited to share a sample of actual rosters they considered to reflect their scheduling practices. When requesting these rosters, it was emphasised that actual, executed rosters (i.e., past rosters that have been completed, including possible post-publication modifications) were favoured, as these are less theoretical and reflect ATCOs' duties compared to planned rosters that have not yet been executed. While the majority of ATSPs were able to share such executed rosters, two ATSPs were only able to share planned rosters due to organisational constraints. All rosters were reviewed in order to select the most relevant sample of rosters for the analysis. A final sample of 24 rosters was selected on the basis of several criteria, including the distribution of ACC, TWR and APP, a balance between individual and team scheduling, the presence of a majority of operational duties and night work, the absence of prolonged periods of vacation days. Trainees' and instructors' rosters were excluded as they were considered not representative of ATCO working hours. The rosters were selected such that they best reflect the current practices of the ATSPs.

The analysis of the roster sample was carried out in three steps:

1. The use of the Dawson's Fatigue Likelihood Scoring Matrix to obtain weekly fatigue scores for each roster.
2. An expert analysis to assess how the rosters take into account scientific principles.
3. The use of the FAID and SAFTE-FAST biomathematical models (BMMs) to obtain a fatigue risk index for each shift in the roster.

More details on the roster analysis method are provided in Annex C.4 and study deliverable D-2.C.2.

The results of the roster analysis enabled the research team to identify fatigue hotspots in the rosters and to select a subsample of ATSPs for participation in the subjective and objective data collection campaigns. To ensure a balanced distribution in the sample of ATSPs in the data collection campaigns, the unweighted criteria were:

- Geographical distribution of ATSPs in four geographical zones in Europe (North, East, South, and West).
- Volume of ACC movements.
- Specific consideration of fatigue risk, expressed as the presence of predictive and/or proactive work, the possibility to report fatigue using a dedicated form, the presence of a fatigue working group and a specific training on fatigue risk.
- A balance of individual and team-based roster construction.
- Flexibility of scheduling, such as pre-publication requests and post-publication swaps.
- Responsiveness in communicating with the consortium members: the ATSPs' ability to effectively coordinate internally and their availability to participate in the study within the given timeframe.
- Average number of hours worked per week.
- Average and maximum day shift length.
- Average number of shifts per month.

Following the selection of ATSPs, adaptations to the initial selection were made due to the unavailability of the ATSPs. Although all the contacted ATSPs showed interest in taking part in the data collection, not all of them were available on the proposed dates and/or timeline. Other ATSPs were therefore contacted on the basis of the same selection criteria.

Step 2: Subjective data collection

In a second step, subjective data collection measurements were conducted with a total of 216 volunteer ATCOs of six ATSPs. All ATCOs at each of the six ATSPs were invited to participate in the data collection through downloading the dedicated Welbees app and assigning for the study. Data was collected on ATCOs' fatigue, sleep and workload for 10 consecutive days during actual operational duties. Upon registering in the campaign, ATCOs filled in a 'profile questionnaire' to collect demographic data, including age and gender (sex) of the participant, their commute habits, years of experience, type of qualification and the ATSP they work at, ratings of their work environment and technology support, ratings of the contribution of the system support and the working position to their workload, and questions regarding their fatigue and sleep.

Every day, the participating ATCOs were asked to fill out their daily events, including sleep, working sessions, stand-by duties, and non-operational duties, such as office duties, simulator sessions, medical checks, training sessions, on-the-job training sessions, and other forms of non-operational work. After each working session, ATCOs were asked to rate their perceived stress, workload, and fatigue, as well as to indicate any factors encountered during the working session from a predefined list of factors. Fatigue was assessed by means of a standardized scale, the Samn-Perelli scale ranging from 1 to 7. A value higher to 6 is associated with performance impairment. **However, it is worth mentioning that the fatigue level threshold of 6 should not be considered as an absolute cut-off as slightly lower fatigue scores could be associated with impacts on ATCOs performance depending on the operational context.**

In addition to this data collection, actigraphy was used on a subsample of volunteer ATCOs to collect objective sleep data to validate the subjective sleep logs of the ATCOs. The approach applied considered ATCO fatigue as a multidimensional construct, and included the collection of data on several contributing factors. More details on the subjective data collection are provided in Annex C .

Step 3: Objective data collection
Third, objective data on ATCO fatigue and performance was collected during objective measurement campaigns at five ATSPs, on 20 volunteer ATCOs during actual operational duties in the operations (OPS) room and control tower. The objectives were to validate the subjective fatigue ratings obtained in the subjective data collection campaign, to analyse the effects of fatigue on ATCO performance, and to determine the feasibility for ATSPs to use objective measurement techniques to measure fatigue in real-time during the ATC operations.

Eye tracking was used to assess fatigue objectively, by means of the outcome measures blink duration, blink frequency, and the Percentage of Eyelid Closure (PERCLOS, Abe et al., 2023). Eye tracking was also used for objective workload assessment by means of the indicators blink frequency and blink duration (Benetto et al., 2011). For the measurements at the ATSPs two types of SmartEye™ eye trackers were used, the SmartEye XO and the SmartEye Pro. These devices use optical tracking supported by infrared light. By means of corneal reflection, they monitor pupil size, pupil shape and the position of the eyelids in real-time, which the software computes into the different outcomes measures. In addition to eye tracking, the 3-minute Psychomotor Vigilance Task (PVT) performance measure was used to assess the effect of fatigue in ATCOs. The PVT was offered to the ATCOs using a dedicated PVT app on a standalone tablet, directly before and after the shift. During the objective measurement procedure, subjective fatigue was also assessed by means of both the Karolinska Sleepiness Scale (KSS) (Åkerstedt & Gillberg, 1990) and the Samn-Perelli Fatigue Scale (SP) (Samn & Perelli, 1982). Workload was assessed by means of the validated Rating Scale Mental Effort (RSME) (Zijlstra, 1993) and the Instantaneous Self-Assessment (ISA) (Legatt, 2023). More details on the objective data collection are provided in Annex C .

5.2 Exposure to fatigue in the actual ATCO rosters

5.2.1 Synthesis of the interviews with ATSPs

This section summarises the findings of the interviews. The sample of 16 ATSPs formed a diverse sample, representative of the EU ATSPs, showing varied arrangements regarding their rostering practices as reported in the interviews. The interviews reveal that:

- The ATSPs’ methods of constructing rosters consists of the use of a dedicated software and/or spreadsheets, and depends largely on the configuration and operational requirements of each ATSP and its units.
- The timing of roster publication varies greatly (between less than 2 weeks and more than 2 months in advance), not only between ATSPs, but between units as well.
- The majority of the ATSPs make regular use of pre-publication requests (i.e., ATCOs can request particular duties in advance) and post-publication swaps (i.e., ATCOs can exchange their duties with other ATCOs after their rosters are published), as long as the modified roster complies with applicable limits and regulations (e.g. work time regulations for shift work on national level, the working time specifications within the collective labour agreements within ATSPs).
- All but one ATSP include night duties in their operations.
- In general, the integration of fatigue management in the rostering procedure is not reported to pose significant organisational constraints to the ATSPs.

- All ATSPs indicated that they have reactive measures in place, whereas the use of proactive measures is clearly much more variable across the ATSPs.
- Regarding predictive and preventive measures for fatigue risk management, while none of the interviewed ATSPs makes use of biomathematical models, a majority does make use of predictive and/or proactive means to manage the risk of fatigue including the use of soft rules to prevent fatigue in the ATCOs schedules.
- Some ATSPs communicate on fatigue management and/or offer complementary courses on fatigue risk management.
- The most reported causes of fatigue according to the ATSPs in relation to the rosters were shift length and night shifts.
- The most common non-roster related factors contributing to fatigue mentioned by ATSPs were workload, complexity of operations, and traffic.
- All interviewed ATSPs acknowledged the role roster construction plays in ATCO fatigue.

5.2.2 Roster data analysis

5.2.2.1 Results of the roster analysis

Step 1: Use of Dawson's Fatigue Likelihood Scoring Matrix to obtain fatigue weekly scores for each roster.
The roster analysis with the Dawson's fatigue likelihood matrix showed that 77% of the analysed roster weeks represent little risk in terms of fatigue, offering good opportunities for sleep, except for a few weeks of some of the rosters. When shifts with long durations are placed at the beginning or end of roster cycles, they generate a higher fatigue risk, as they extend the wake period and thus reduce opportunities for rest, which is contrary to what is scientifically recommended.

Step 2: Expert analysis to assess how the rosters take into account scientific principles.
The expert analysis did not highlight any scheduling criteria that were particularly deviating from scientific recommendations regarding shift schedules used by the ATSPs. Some of these principles include the 8 mandatory roster elements (night duties, rest time between duties and duty length). The shifts seem to be evenly spread within the rosters and the amount of consecutive night shifts rarely exceeds two. The rest time before or after a night shift however showed that it was not always adequate to allow for effective recovery. The number of hours worked per week proved rather irregular, for which it may be worthwhile to work on a better balance between the working hours per month, and to avoid weeks that are too busy and difficult to recover from. In terms of direction and speed of cycle rotation, the majority of rosters conform to the scientific recommendation of a clockwise, fast-paced cycle rotation. Most analysed rosters contained sufficiently long rest periods in between duties as well. The summary of the findings of the expert analysis are presented in Table 5-1[18].

[18] More details of the roster analysis results can be found in study deliverable D-2.C.2.

Table 5-1: Summary of findings of expert analysis.

Expert analysis criteria	Findings
Long periods of duty	- The mean shift length of all analysed shifts is 8 hours and 14 minutes. - Some duties last over 11 hours, but are always followed by adapted rest periods. - Long duties are mostly night duties and stand-by duties.
Night duties and night work	- All but one included ATSPs operate on night duties, but not in all centres. - Only few night duties in the rosters, **never more than two consecutive nights**. - Night duties are among the longest in the rosters, but often preceded or followed by opportunities to get a full night's sleep. - The rest times framing a night shift do not always allow for effective recovery, especially when scheduled in the middle of a cycle or after short rest periods.
Early duties	- Early shifts are observed in all rosters, **but none start before 0500** local time. - Consecutive early shifts are generally limited to 2 or 3 in a row. - Early shifts are typically positioned at the beginning of the cycle, encouraging physiological adaptation. - Consecutive early shifts are often accompanied by rest days to mitigate their impact if operational constraints necessitate such scheduling.
Shortest time between two duties	- Overall, the majority of the sample has **more than the recommended 16 hours** of rest between shifts, but all ATSPs have rosters with short rest periods (<16hours). - Only one roster has a critical rest period of less than 10 hours.
Working hours over seven days	- The mean number of hours worked observed is 35 hours 36 minutes per week, with a very large variability of weeks ranging between 13 and 65 hours. - Most of the rosters in the sample include weeks of more than 40 hours. - The average maximum consecutive working days indicated by ATSPs is around 6 (see section 2.4). However, the actual roster analysis revealed that the ATSP's roster cycles studied rarely exceed 5 consecutive working days.
Direction and speed of rotation	- The majority of ATSPs draw up their rosters clockwise, others counter-clockwise, and some others use a mixed system. - The majority of rosters **have a fairly fast pace of 2 or 3 similar shifts** before moving on to another type of service. Slow rotations are in the minority.
Rest days	- The rosters analysed regularly contain **rest periods of at least 2 days**. - Only 1 ATSP seems to have an irregular organisation of rest days. - The rosters of 13 ATSPs contain isolated rest days, more or less well adapted for sleep opportunities.

<u>Step 3: Use of the FAID and SAFTE-FAST models to obtain a fatigue risk index for each shift in the roster.</u>
The assessment of the duties by means of the two biomathematical models showed a maximum score of around 8 out of 9 for both BMMs, with around 85% of shifts associated with a low to moderate risk of fatigue, meaning that 15% of the rosters analysed are associated with the high risk fatigue according to the BMMs.

5.2.2.2 Discussion of roster analysis results

In the analysis, diverse practices in roster construction, publication timing, and fatigue management strategies were observed. Most rosters appear to be based on a clockwise and fast-paced cycle rotation. Shift length and night shifts are identified as primary contributors to ATCO fatigue, both in the expert analysis as in the biomathematical analysis. The Dawson's fatigue likelihood scoring matrix provides results for weeks. It shows a maximum score on the rosters of 25 out of 40, with 77% of the weeks associated with a low risk of fatigue. The biomathematical models provide results for duties. The assessment of the duties by means of the biomathematical models show a maximum score of around 8 out of 9 for both BMMs, with around 85% of shifts associated with a low to moderate risk of fatigue. The scores generated by both biomathematical models tend to be similar, as, overall, the BMMs evaluate the various scheduling criteria analysed throughout the process in the same way. When comparing the analysis of the BMMs and the expert analysis, the main similarity relates to usage of night shifts: both the BMMs and the expert analysis consider night shifts to be particularly fatigue-generating. Furthermore, in general, both the expert analysis and biomathematical analysis conclude that the current rosters applied in the sample ATSPs provide good sleep opportunities. It is, however, important to consider the whole organisation of the roster to verify the potential risk generated by this type of shift, as well as the role cumulative fatigue and other factors may play in fatigue levels.

The other criteria analysed, i.e. long periods of duty, early shifts, rest time between two shifts, working hours over seven days, direction and speed of rotation, and rest days are not directly taken into account by the BMMs, it is therefore not possible to compare their results with those of the expert analysis.

The interviews and roster analysis have supported the establishment of several research hypotheses, which were subsequently verified through subjective and objective measurements with the ATCOs of six ATSPs that were invited to take part in data collection campaigns.

For each of the final six ATSPs involved in the subsequent measurement campaigns, fatigue hotspots were identified. Such fatigue hotspots are defined as shifts that show an increased risk for fatigue according to the results of the BMM analysis and expert analysis of their rosters. The main hotspots in the six ATSPs are night shifts, which are particularly fatiguing because they run counter to the human biological clock and generate levels of fatigue that are considered critical according to scientific standards. Other hotspots, such as early shifts or split shifts, are also in use in some of the six ATSPs. Although they did not generate critical levels of fatigue in the quantitative roster analysis, this type of shift was also chosen for the objective measurement campaign.

5.2.2.3 Key findings from roster analysis

The roster analysis aimed at analysing a sample of actual rosters from a representative sample of 16 ATSPs. The sample of rosters features rosters that reflect the main fatigue factors to which European ATCOs are exposed. The 16 ATSPs selected for the roster analysis form a diverse sample regarding their social context and type of operations. They showed varying arrangements regarding their rostering practices and level of fatigue risk management maturity. Based on the rosters provided by the ATSPs, a thorough analysis was performed by means of the Dawson's fatigue likelihood matrix, an expert analysis, and two biomathematical models.

The following conclusions can be drawn based on the roster analysis:

- The roster analysis with the Dawson's fatigue likelihood matrix showed that a large majority of the analysed rosters led to a low risk in terms of fatigue and offered good opportunities for sleep (**77% of the weeks analysed was associated with a low risk of fatigue**).
- The expert analysis showed that **most rosters applied the scientific recommendations regarding scheduling relatively well** (e.g. regarding direction and speed of cycle rotation).
- The scores generated by the biomathematical models SAFTE-FAST and FAID were quite similar (**around 85% of the shifts analysed were associated with a low to moderate risk of fatigue**).
- When comparing the analysis of the BMMs and the expert analysis, both considered night shifts to be particularly fatiguing.
  The expert analysis addressed also other factors, considering the whole organisation of the rosters, the role of cumulative fatigue, and specific roster criteria (long period of duty, early shifts, rest time between two shifts, working hours over seven days, direction and speed of rotation, and rest days). **When evaluating rosters, it is therefore important to combine these two types of analysis wherever possible, as they appear to be complementary, and not to rely on BMMs alone.**

5.3 Exposure to fatigue and fatigue factors in actual ATCO operations

5.3.1 Description of data sample

216 ATCOs participated to the subjective data collection campaign. This represents a mean participation rate of around 7% of the population of each ATSP, in line with other studies having applied a similar data collection methodology on several consecutive days. Table 5-2 summarises the main demographical characteristics of the ATCOs sample in comparison with the general population of the ATSPs. The sample contains 131 Tower controllers, 135 Approach controllers, and 91 Area controllers. Note that some participants have endorsements for more than one position. Of these participants, 37% are female and 63% are male, which points at a slight

over-representation of female ATCOs in the study when compared to the whole population of the participating ATSPs. The ages are rather evenly distributed, with participants having a mean age of 39.6 years.

Table 5-2: Demographic parameters of the ATCOs sample.

Parameter		Sample population	Sample proportion	Population of the six ATSPs
Gender (sex)	Male	137	63 %	71 %
	Female	79	37 %	29 %
Age (in years)	20 – 30	41	19 %	15 %
	31 – 40	80	36 %	25 %
	41 – 50	72	34 %	36 %
	51 – 60	22	10 %	17 %
	61 – 70	0	0 %	1 %
ATCO job position	ACC	125	58 %	50 %
	TWR	81	38 %	43 %
	APP	fdu85	39 %	44 %

In total, 1,445 duties were recorded, including 288 non-operational duties. A total of 2,416 work sessions were recorded, of which 2,248 were complemented with a fatigue assessment. One work session is defined as a period of continuous work at the working position; two or more work sessions, usually separated by a break, form one operational duty. After each work session, the ATCOs are asked to rate their fatigue. Table 5-3 summarises the recorded events and their frequencies. Non-operational duties include office duties, simulator sessions, medical checks, training sessions, on-the-job training sessions, and other forms of non-operational work. **These non-operational duties account for 20% of the total working time**.

Table 5-3: Events recorded with the app.

Event	Frequency	Proportion of total events
Work session	2416	47 %
Sleep	2031	39 %
Non-operational duty	288	6 %
Stand-by duty	57	1 %
Day off/ holiday	371	7 %
Sick leave	16	< 1 %
Total	5179	100 %

The distribution of all fatigue scores appears homogeneous between ATSPs and the participating ATCOs show a satisfactory participation despite the constraints imposed by this data collection, requiring them to enter data every day. The confidence level is very high in the collected data. The representativeness of the samples is considered as satisfactory and the results obtained on this sample of ATCOs may therefore be generalised to the ATCOs general population.

The analysis of the data consists of an univariate linear analysis for all fatigue data, followed by a relative risk analysis for data containing critical fatigue scores. The linear analysis, carried out on the entire fatigue data, investigated whether certain parameters significantly increased the fatigue levels found. The linear evaluation is expressed as the absolute increase or decrease of fatigue (expressed as points on the fatigue scale) in accordance with fluctuations of a parameter. The risk analysis, based on models commonly used in epidemiological and risk research, investigates the impact each parameter may have on the relative risk of obtaining a critical fatigue score (i.e., scores of 6 or 7 on the SP scale). The evaluation is expressed as the proportional increase or decrease of the risk on critical fatigue (expressed in percentages) according to the fluctuation of a parameter.

The analyses on the fatigue contributing factors were separated between factors that are not related to ATCOs work, i.e. individual factors, and factors related to ATCOs' work. Within the investigated factors relating to ATCOs' work, a differentiation is made between roster-related factors and non-roster related factors. The effect on fatigue levels and critical fatigue risk is univariately investigated for each of the parameters included in Table 5-4.

The choice for these parameters is based on the previous findings of the study. For roster related parameters and non-roster parameters, both a linear and relative risk analysis were carried out on the acute fatigue levels reported in each event. Conversely, for more stable parameters, such as demographic parameters, this approach was not considered to be relevant. Indeed, acute fatigue is per definition the level of punctual fatigue at one given time, accounting for many varying circumstances. Combining stable parameters such as demographic information with this variable would not prove to be statistically relevant. Therefore, it is opted for an approach investigating the impact of the demographic parameters on *chronic* fatigue levels instead. These chronic fatigue levels were provided once by the participants in the profile questionnaire.

It is important to note that, even if small, individual factors may multiply and emphasise each other in a combined context. Even if it is found that one parameter has no significant impact on fatigue, it still might trigger other parameters when the parameters are increased. **This accentuates the precaution that must be taken regarding risks that may compound one another.**

The relative risk could be confidently calculated given the observed data, but this confidence level is weaker for predicted values. It is crucial to acknowledge and address certain uncertainties and limitations that impact the robustness of the predictions. One notable limitation is the insufficient representation of cases of critical fatigue within the dataset. As the predictive model relies heavily on the availability of diverse and comprehensive data to make accurate extrapolations, the model might lack the necessary depth to confidently predict outcomes in hypothesised situations. Therefore, hypothesised effects can only be speculated as increases in risk may not be linear. For example, it is difficult to predict what would be the effects of very long duties if they are not included in the data sample. As this research study is observational and not experimental, it is not possible to compare given scores with any valid control group. In some cases, a lack of data can thus also be observed due to the ATSPs' different practices regarding fatigue.

Like any scientific study conducted in the field, certain limitations should be emphasised to ensure a realistic understanding of the predictive capabilities of the analysis:

- Since the study relies on voluntary participation, a selection bias cannot be excluded; participants in the study might be more sensitive to the issue of fatigue.
- The number of data points is sometimes too low to draw conclusions on specific parameters.
- As the research is based on an observational study, it is difficult to extrapolate the effects of values exceeding the existing/observed values.

Table 5-4: Parameters included in the study analysis of fatigue levels and critical fatigue risk.

Parameters included in the analysis		
Non-work related parameters[19]	Age	
	Gender (sex)	
	Job position	
	Commute time (in minutes)	
	Experience (in years)	
	Perception of the work environment	Equipment quality
		Quality of the working environment
		Quality of the rest facilities
		Technological support of the working position
Roster related parameters	Duty type	Duty types as defined by the ATSPs
		Duty types as defined by the data
	Sleep	
	Non-operational duties	

[19] The study analysed work-related factors, although it is acknowledged that personal factors such as family composition, living conditions, commute time etc. may have an impact on fatigue.

	Consecutive duties	
	Duty length	
	Work session length	
	Duty-to-break ratio	
	Rest between duties	
	Consecutive night work	
	Rest after night work	
	Rest within a cycle	
Non-roster related parameters	Workload	
	Factors encountered during the duty[20]	Difficult weather conditions
		High traffic density
		High traffic complexity
		Low traffic volume
		Uneventful, monotonous traffic
		Difficult or much coordination with colleagues or other centres
		Coordination with management
		One or several specific flights
		Traffic unpredictability
		Sector opening/closing
		Issues with tools and/or equipment
		Time pressure/Delays
		Unexpected events
		The absence of all these factors

5.3.2 Analyses

5.3.2.1 Prevalence of fatigue

In this section the results of the data analysis are presented. For understanding fatigue levels and contribution of fatigue factors it is noted that the data analysis quantified fatigue risk level associated with each contributing factor in two ways:

- Average fatigue level: The effect on the average fatigue level on the total sample; it gives the contribution of each fatigue factor expressed in number of points on the Samn-Perelli (SP) scale.
- Critical fatigue level: The risk for each factor to produce a critical fatigue level (>6 on the Samn-Perelli scale), expressed in % of increased risk compared to the average 5.6%.

In general, the average fatigue level found in this study proved to be quite low, with a mean Samn-Perelli scale (SP) level of 2.78 points (range 1-7) for operational duties. The analysis of current rostering practices predicted a risk of high fatigue (SP > 5) in 15% of duties, while the data collection on a representative sample of ATCOs showed that 5.6% of duties were actually associated with a risk of high fatigue. In the sample, 63 duties contained critical fatigue scores, as defined as scores higher than 5 on the Samn-Perelli scale. This represents 5.6% of the total sample of recordings. It is worth mentioning that the fatigue level threshold of 6 should not be considered as an absolute cut-off as slightly lower fatigue scores could be associated with impact on ATCOs performance depending on the operational context. In terms of fatigue exposure, the results from the data collection align with the results from the roster analysis, demonstrating that **only a few duties are associated with a high risk of fatigue**. Therefore, these results suggest that current ATSPs' practices in terms of fatigue management are effective in controlling fatigue risk. In further analyses, **the baseline risk of scoring a critical level of fatigue may thus assumed to be at 5.6%.**

[20] Single person operations was not included in the study.

5.3.2.2 Roster-related factors

Table 5-5 presents the variations of the relative risk of critical fatigue for several roster related parameters, including the eight roster elements defined in the ATCO fatigue-related regulatory requirements. For each parameter, it was calculated how the baseline risk would vary when the parameter changes.

*Table 5-5: Summary of roster related parameters, risk coefficient and significance. The significance is reported for the following levels: * p < 0.05; ** p < 0.01; *** p < 0.001; NS: Not Significant[21].*

Roster-related parameter			Relative risk of critical fatigue	Significance
Duty type	As defined by the ATSPs	Evening duties	–24% for every evening duty	< 0.001 ***
		Night duties	+253% for every night duty	< 0.001 ***
	As defined by the data	Morning duties	+289% for every morning duty	0.02 *
		Night duties	+333% for every night duty	< 0.001 ***
8 roster elements	Duty period length		+10% for every additional duty hour	< 0.001 ***
	Rest period after duties encroaching the night time		–43% for every additional rest day after a night duty	0.06
	Consecutive duties		+27% for every additional working day	0.08
	Work session length		+33% for every additional hour in one work session	0.09
	Ratio of duty periods to breaks		NS	0.19
	Rest between duties		NS	0.28
	Consecutive duties encroaching the night time		NS	0.49
	Number of rest periods within a roster cycle		*Insufficient data for analysis*	

	Roster-related factors	ACC Average	TWR Average	Variation risk of critical fatigue (%)
8 Roster Elements	Maximum consecutive working days with duty (days)	5.9	5.8	Every additional working day increases the risk of critical fatigue by 27%.
	Maximum hours per duty period (hours)	9.2	10.5	No effects observed in the collected data.
	Maximum time providing ATS service without breaks (mins)	90	154	Every additional hour in one work session increases the risk of critical fatigue by 33%.
	Minimum duration of rest periods (hours)	11.6	12	No effects observed in the collected data.
	Maximum consecutive duty periods encroaching the night-time (days)	2.3	2.9	No effects observed in the collected data.
	Minimum rest period after a duty period encroaching the night-time (hours)	22.5	17.8	No effects observed in the collected data.
	Minimum number of rest periods within a roster cycle	3.7	3.7	Each additional day of rest following a duty encroaching nighttime reduces the risk of critical fatigue in the next duty by 43%.
	Ratio of duty period to breaks	0.69	0.72	No effects observed in the collected data.
Other Factors	Duty type	-	-	Night duties significantly increase the risk of critical fatigue by 253%.
	Sleep debt	-	-	For each 10% of sleep debt, increases the risk of critical fatigue by 80%.
	Non-operational duties	-	-	No effects observed in the collected data.

Table 5-6: Fatigue risk factors and related fatigue index.

[21] Not Significant means that with the current data set, the statistical analysis reveals no impact. This could be due to an absence of effects or to a too small sample size.

Non-roster-related factors		Variation risk of critical fatigue (%)
Workload		Increases fatigue moderately.
Factors encountered during the duty	Difficult weather conditions	Increases the risk of critical fatigue by +192%.
	High traffic density	No effects observed in the collected data.
	High traffic complexity	No effects observed in the collected data.
	Low traffic volume	No effects observed in the collected data.
	Uneventful, monotonous traffic	Increases the risk of critical fatigue by +120%.
	Difficult or much coordination with colleagues or other centres	No effects observed in the collected data.
	Coordination with management	No effects observed in the collected data.
	One of several specific flights	No effects observed in the collected data.
	Traffic unpredictability	No effects observed in the collected data.
	Sector opening/closing	No effects observed in the collected data.
	Issues with tools and/or equipment	No effects observed in the collected data.
	Time pressure/delays	No effects observed in the collected data.
	Unexpected events	No effects observed in the collected data.
	The absence of all these factors	No effects observed in the collected data.

Table 5-7: Fatigue risk factors and related fatigue index.

Regarding the main contributing factors, it is clear that the parameter linked to the duty type has the highest impact on fatigue. Based on the change of fatigue levels across different times of the day observed in the data sample collected in the subjective measurement campaign, three duty types were distinguished. The shift types were thus identified by a data-driven approach. Based on the data collected during the subjective measurement campaigns, three distinct shift types regarding their impact on fatigue can be distinguished:

- Morning duties: duties starting between 02:00 and 06:00 local time.
- Day duties: duties starting after 06:00 and ending before 02:00 local time.
- Night duties: duties ending between 02:00 and 11:00 local time.

This shift types correspond to three different main levels of fatigue and may guide ATSPs in the construction of their rosters (See Chapter 6). They are different from the definition of night duty (00:00 – 05:59) provided for in the Regulation and are not necessarily in contradiction.
As expected, morning and night duties significantly increase the risk of critical levels of fatigue occurrences when compared to the effect day duties have on fatigue. This is consistent with previous research showing that these two types of duties lead to circadian disruptions and sleep deprivation. On the contrary, when testing the impact of evening duties as defined by the ATSPs, a significantly lower level of fatigue is observed. This is mainly explained by the fact that evening duties fall in the so-called Wake Maintenance Zone, known to increase alertness and performance (Zeeuw et al., 2018) even after prolonged sleep deprivation.

The data collection identified other factors that increase the risk of critical fatigue, in particular the number of consecutive working days with duty (+27% for every additional working day) and the hours per duty period (+10% for every additional worked hour).
In contrast, the number of rest days after a night duty significantly reduce the risk of occurrences of critical levels: for every additional day of rest after a duty encroaching the night time, the risk of critical fatigue in the next duty decreases by 43%.

5.3.2.3 Demographic factors

While demographic parameters seem to be evenly distributed across the sample, only a few of the parameters appear to exert a notable influence on chronic fatigue levels. Neither gender, age, nor experience significantly influence chronic fatigue levels. The demographic parameters that stand out are commuting time and perception of the work environment: an increase in the average commuting time increases chronic fatigue levels slightly but significantly, while increasing the perception of the quality of the work environment appears to reduce chronic fatigue significantly. Differences in job position (Tower, Area, Approach) do not impact fatigue levels in this analysis.

Higher age showed to have a marginal effect on fatigue, although previous research has shown that age decreases tolerance to shift work. This finding might be due to a ‘healthy worker effect’ masking the age effect, i.e., individuals still working as ATCOs at a higher age are most tolerant to shift work. Another explanation is that, with age, ATCOs may have more non-operational duties (e.g., administrative, training), reducing their exposure to shift and/or night work and therefore fatigue.

5.3.2.4 Sleep

The impact of sleep on fatigue levels and critical fatigue risk was also analysed. For this impact, more than just sleep duration should be regarded. Indeed, analysing only data on sleep duration would not account for individual variability regarding sleep need. Seven hours of sleeping time may reflect a normal sleep duration for one individual, while it may correspond to a sleep deprivation of one hour for an individual who needs eight hours of sleep. To account for this fact, individual variability in sleep needs, sleep debt, or sleep loss was used to conceptualise sleep in the analysis. Sleep debt is calculated as a percentage of sleep durations compared to the associated individual sleep need. Positive values represent the proportion of sleep that is missing to achieve one's sleep requirement. For example, a sleep debt of 25% for ATCOs who indicated needing eight hours of sleep per night represents a sleep debt of two hours, meaning they slept six hours and are missing two hours (25%) of sleep. Conversely, a negative percentage indicates that the participant slept more than their usual sleep need, which reflects a recovery process. In the analysis, naps and main sleep periods are added to the total amount of sleep if the former occurred less than 24 hours before the duty.

Very high correlation values between actigraphy data and subjective data were found, validating the assumption that conclusions for the sub-sample of ATCOs who participated in the actigraphy could be applied to the entire population of participating ATCOs. A significant effect was found for the effect of sleep debt on critical fatigue risk. The risk analysis showed that, for each 100% sleep debt, the risk of critical fatigue increases by 863%. In other words, for each additional 10% of sleep debt, the risk of critical fatigue increases by 86.3%.

5.3.2.5 Operational fatigue factors

When examining non-roster or operational factors, it appears that their effect on the average fatigue level is as follows: monotonous traffic situations (+0.15 points), high traffic complexity (+0.13 points), and coordination with colleagues or other centres (+0.12 points) are the factors that most significantly increase fatigue levels. In addition, for two of these factors the risk to produce a critical fatigue level is as follows: monotonous traffic situations (+120%) and difficult weather conditions (+192%) increase not only fatigue levels but also critical fatigue risk. (Note: for the factor coordination with colleagues or other centres no effect was observed in the collected data.)

5.3.2.6 Impact of current ATCO supporting technology

The potential impact of current ATCO supporting technology on ATCO fatigue was assessed in this study. As part of the data collection in the subjective measurement campaign, 217 ATCOs responded to a questionnaire related to the equipment and technology available to them.

The impact of the technology support at ATCO workstations was assessed both on ATCO workload and on ATCO fatigue. Experienced workload and fatigue were thus measured in separate questions, just as their ratings of the technology support available to them. ATCOs were asked to rate their experiencing without considering the specific source of their workload and/or fatigue levels, so they were not asked to elaborate on the expected source of their fatigue and workload levels. The answers to the questions related to equipment and technology level were correlated to the answers of the respondents with respect to work-related fatigue, leading to the following conclusions.

<u>Workload</u>: when asked about the contribution of a system support tool at their working position to their overall workload, a large portion of the ATCOs reported that the system support tools lead to a reduction in workload (nearly 40% of the respondents), and a smaller group of ATCOs reported a significant reduction (around 8%). On the other hand, a significant portion of ATCOs reported experiencing only a limited impact (22% of respondents), an increase (24% of respondents) or a significant increase (9% of respondents). When asked about the overall technology support of their working position compared to other ATSPs, 31% of respondents indicated that they feel the technology support at their ATSP is ‘advanced’, 44% of the respondents classified

it as 'moderate' and 25% of the respondents as 'basic'. When relating this to the contribution of the system to workload, it was found that ATCOs who rate the technology level as 'advanced' tend to view the technology as a factor to help reduce their workload. On the other hand, ATCOs who rated their technology support as 'basic' tend to see it as something that can increase their workload, all in all suggesting that a more advanced level of technology support may have a positive effect on perceived workload.

<u>Fatigue</u>: however, the ATCOs responses did not indicate any significant effect of supporting technology on fatigue. When comparing reported fatigue levels to the rated level of technology, no correlations were found in the responses to the questionnaire. The fatigue rating reported by ATCOs was similar regardless of the technology level at the ATSP (rated as basic, moderate or advanced). However, when ATCOs were asked about their opinion of the quality of the equipment, a small correlation was found between the quality of the equipment and the reported fatigue. Moreover, in terms of ATCO working environment, a correlation was also found. ATCOs who rated their working environment negatively also tended to respond that they experienced fatigue more often in comparison with ATCOs who had a positive view on their working environment. More details on reported fatigue and workload levels in relation to the available technological support can be found in the study deliverable D-3.A.

With that said, it is not feasible to isolate the contribution of technology to ATCO fatigue from other contributing factors that may influence an ATCO's fatigue level, nor is it possible to objectively quantify the contribution of technology to fatigue levels or critical fatigue risk.

5.3.3 Key findings on exposure to fatigue and fatigue factors

From the roster analysis and the field data collection, the following conclusions are drawn:

- The roster analysis with the Dawson's fatigue likelihood matrix showed that a large majority of the analysed rosters led to a low risk in terms of fatigue and offered good opportunities for sleep (**77% of the weeks analysed was associated with a low risk of fatigue**).
- The expert analysis showed that **most of the current rosters already apply the scientific recommendations regarding scheduling relatively well** (e.g. regarding direction and speed of cycle rotation).
- The scores generated by the biomathematical models SAFTE-FAST and FAID were quite similar (**around 85% of the shifts analysed were associated with a low to moderate risk of fatigue**). Note: The biomathematical models provide results for duties, whereas the Dawson's fatigue likelihood scoring matrix provides results per week.
- When comparing the analysis of the BMMs and the expert analysis, both considered night shifts to be particularly fatiguing.
- The expert analysis addressed also other factors, considering the whole organisation of the rosters, the role of cumulative fatigue, and specific roster criteria (long period of duty, early shifts, rest time between two shifts, working hours over seven days, direction and speed of rotation, and rest days). **When evaluating rosters, it is therefore important to combine these two types of analysis wherever possible, as they appear to be complementary, and not to rely on BMMs alone.**
- In general, mean fatigue was found to be quite low, **with 5.6% of the studied duties associated with a critical level of fatigue**.
- In terms of fatigue exposure, the results show a lower level of fatigue than predicted by the roster analysis. This finding suggests that current ATSP fatigue management practices are quite effective in managing fatigue risk in the majority of the ATSPs.
- Even if the number of duties associated with a critical level of fatigue is rather low, the duties showing a critical level of fatigue need to be investigated and addressed.
- Demographic factors did not appear to significantly affect chronic fatigue as measured subjectively at baseline. Age showed to have a marginal effect on fatigue, while gender did not seem to be associated with fatigue. The individual factors that did show to significantly affect fatigue were commuting time and the perception of the working environment.
- Regarding the main contributing roster-related factors, it was shown that **morning and night duties significantly increased the risk for critical levels of fatigue** when compared to day duties. This is consistent with previous research showing that these two types of duties can lead to sleep/wake

disruptions and sleep debt (Härmä et al, 2002). Night duties significantly increase the risk of critical fatigue by 253%, compared to the baseline risk[22] measured on the average data.

- Considering the eight roster elements in the ATCO fatigue regulatory requirements, it appeared that a significant increase of risk was associated with two elements: the **number of consecutive working days**, and the **number of hours per duty period**. The **number of rest periods after a duty period encroaching the night time was shown to significantly reduce the risk for critical levels of fatigue**. These findings are also consistent with previous literature on shift-work in other domains. Key findings are presented in Table 5-6:
    - **Maximum time providing Air Traffic Control service without break**: Every additional hour in one work session increases the risk of critical fatigue by 33% compared to the baseline risk.
    - **Maximum consecutive days with duty**: Every additional working day increases the risk of critical fatigue by 27%.
    - **Minimum rest period after a duty period encroaching the night time**: Each additional day of rest following a duty encroaching night-time reduces the risk of critical fatigue in the next duty by 43%.
- The ratio of duty periods to breaks, the minimum duration of rest periods, the maximum of consecutive duties encroaching the night time, and the minimum number of rest periods within a roster cycle **were not found** to significantly increase or decrease the risk of critical fatigue, presumably because they did not vary much in the dataset
- Sleep debt was shown to be a strong predictor of fatigue as every additional percent of **sleep debt increased the risk of critical fatigue by 8%. This highlights the importance of managing the duration and quality of sleep for ATCOs.**
- Among the **non-roster** related factors the following increase the most the ATCOs fatigue risk: monotonous traffic situations, high traffic complexity, difficult weather conditions, and coordination with colleagues and/or other ATC centres. In particular:
    - Difficult weather conditions (low ceilings, limited visibility, high or gusty winds, or thunderstorms) increase the risk of critical level fatigue by 192%.
    - Monotonous traffic situations (uneventful or repetitive work conditions) increase the risk of critical fatigue by +120%.

5.4 Objective fatigue and performance measurements in real-time

5.4.1 Validity of the subjective rating scales

The objective data collection was performed with a representative sample of 20 participants, consisting of both males and females of different types of units, age categories and levels of experience. Measurements were conducted during night shifts mostly (60%) because these were identified as the main fatigue hotspots in the roster analysis. Other measurements were conducted during evening (30%) and split shifts (10%). Regarding unit type, 12 Approach and 8 Tower controllers were included. The objective measurements were conducted using remote eye tracking throughout the shifts, and the PVT reaction time task (before and after the shifts). The subjective measurements during the fatigue hotspot shifts showed that the mean sleepiness and fatigue experienced was moderate ('neither sleepy nor alert' / 'a little tired, less than fresh'), and below critical levels for the majority of the time. Mean workload showed to be moderate to low. A clear increase in fatigue could be seen throughout the shift, shown by the difference between mean subjective fatigue levels before and after the duty, and the corresponding PVT metrics calculated.

For the fatigue assessment, the results of the eye tracking analyses showed that there was a significant correlation between both the subjective fatigue and sleepiness ratings and the percentage of the time the eyes were closed (PERCLOS). This finding **substantiates the validity of the subjective fatigue ratings that were used in the subjective data collection campaign**. This finding is also in line with the outcomes of previous studies, indicating that the time during which the eyes are closed for a certain percentage increases with the onset of

[22] The baseline risk is defined as the 5.6% of risk of critical fatigue measured on the average values of the data sample presented in Table 2.1, p. 29. See also Table 5.6 p.53.

fatigue (e.g. Zhang et al., 2021). In addition, PERCLOS has been found to be one of the most reliable and valid indicators of fatigue (Hu & Lodewijks, 2020).

With regards to workload, the results did not show any significant correlations between the eye tracking metrics and the subjective workload ratings. Other eye tracking parameters, derived from pupillography (e.g. pupil diameter) might be better able to capture experienced workload and should be validated in future studies.

In addition, no significant correlations between the subjective fatigue and sleepiness ratings and the PVT metrics were found. This finding suggests that subjective feelings of fatigue do not necessarily correspond with sustained alertness as measured by a reaction time task. It is possible that other factors, such as individual differences in cognitive processes, influence this relationship, which corresponds with previous findings (Van Dongen et al., 2011; Wehrens et al., 2012).

In conclusion, the results of the objective data collection campaign proved that the subjective fatigue and sleepiness ratings applied in the previous steps of the study are valid measures for fatigue and sleepiness detection in ATCOs. The findings from the objective measurements also underlined that different types of fatigue related outcome measures (subjective, objective, performance based) can reflect different concepts. They are therefore not so much interchangeable, should rather be seen as complementary to one another, and could therefore be measured alongside each other to study the effect of fatigue on performance.

5.4.2 Feasibility of eye tracking measurements in ops room and control tower

The study specifications requested to verify whether objective measurements, such as eye tracking, could be recommended as a tool for ATSPs to monitor and detect fatigue in the OPS environment. Because of the organisation and expertise needed, as well as the burden for the ATCOs, it was concluded that it is difficult to implement eye tracking as used in this study in daily ATSP operations. The experiments needed to be conducted by at least two researchers at each ATSP. In addition, it took two to four days to prepare the measurements, setup the equipment, instruct the participants, monitor the measurements during the shifts, and wrap up afterwards. As a result, the measurements were time-consuming and laborious, while the set-up used led to several operational challenges. Nevertheless, the eye tracking data proved to be of reasonable quality, although some data needed to be excluded because the eyes could not be detected, for instance because the participant looked away from the navigation screen.

Despite the difficulties raised, the setup that was applied could be used for scientific purposes, studying fatigue during a limited period in the OPS room (e.g. with the help from external experts). It would be interesting to see if new technologies under development for real-time objective fatigue monitoring could be applied in the OPS room (e.g. wireless EEG, speech analysis, or web-cam based eye tracking), although the number of studies that used and validated these techniques is still scarce, and further research is needed.

5.5 Discussion of results on ATCO fatigue in current operations

In summary, this second part of the study aimed to collect scientific data on the prevalence of ATCO fatigue, and to conduct a detailed analysis on the contributing factors, causes and consequences.

Data collection
By means of a comprehensive subjective data collection campaign with ATCOs of six ATSPs, the level of fatigue, causes and relative contribution of different factors were studied. The ATSPs that were included represented different geographical regions, volume of traffic movements, fatigue management maturity, types of scheduling, and various rostering characteristics. The 216 participating ATCOs (participation rate of 7%) proved to be representative with respect to the overall population of ATCOs within the participating ATSPs. The data collection was conducted over 10 consecutive days, covering individual, roster and non-roster related factors related to fatigue.

Observed average fatigue level and critical levels of fatigue

In general, the average fatigue level found in this study proved to be quite low, with a mean Samn-Perelli (SP) fatigue scale level of 2.78 points (range 1-7) for operational duties. The analysis of current rostering practices predicted a risk of high fatigue (SP > 5) in 15% of duties, while the data collection on a representative sample of ATCOs showed that 5.6% of duties were actually associated with a risk of high fatigue. The average fatigue levels and prevalence of critically high fatigue levels found can be considered relatively low when compared to for instance aircrew or healthcare professionals. In previous studies of aircrew using the same methodology, the percentage of critical fatigue levels was shown to range between 12 and 15% of the measured duties (Cabon & Somvang, 2017). Since few duties were associated with a risk for critical fatigue, current workload and fatigue management practices by EU ATSPs seem to be quite effective. Workload and fatigue management by ATSPs is indeed generally conducted from an integral ATM perspective and is applied at a strategic and pre-operational level, for example by means of pro-active working position staffing (i.e. seat rotation, combining and splitting sectors, extra staff during busier shifts etc.).

Roster-related fatigue factors

Regarding the main contributing roster-related factors, it was shown that morning and night duties significantly increased the risk for critical levels of fatigue when compared to day duties. This is consistent with previous research (Li et al., 2021) showing that these two types of duties can lead to sleep/wake disruptions and sleep debt. Other factors that increased the risk of critical fatigue were the number of consecutive working days, and the number of hours per duty period. The number of rest periods after a duty period encroaching the night time was shown to significantly reduce the risk for critical levels of fatigue. These findings are also consistent with previous shift-work literature that has demonstrated that at least two consecutive rest periods are needed to recover from night shifts (Vedaa et al., 2017).

The ratio of duty periods to breaks, the duration of rest periods, the number of consecutive duties encroaching the night time, nor the number of rest periods within a roster cycle were found to significantly increase the risk of critical fatigue. These findings were however strongly limited by the dataset as ATSPs are already controlling these parameters.

Demographic factors

When analysing the contribution of various factors to the critical levels of fatigue, the results show that individual or demographic factors did not appear to significantly affect chronic fatigue. Age showed to have a marginal effect on fatigue, while gender did not seem to be associated with fatigue. The marginal effect of age on ATCOs fatigue is consistent with the results of a recent study on aging ATCOs (Cabon et al, 2024). One explanation for this result is that individual and organisational strategies tend to overcome the negative effects of age on sleep quality and tolerance to shift work. This result can be also explained by the "healthy worker effect", i.e. the fact that ATCOs are more medically controlled than the general population and that as a result, the healthier ATCOs of older age remain a part of the workforce. However, given the fact that a trend can be seen in which it is considered to increase the retirement age of ATCOs, implementing appropriate age dependent fatigue management practices and possibilities to adjust rosters for the older population of ATCOs remains important.

Individual factors that did show to significantly affect fatigue were commuting time and the perception of the working environment (e.g., lighting, noise, and temperature). Commuting time will specifically affect fatigue in relation to night shifts and (early) morning shifts, as a longer time needed to commute will reduce the possibility to get sufficient sleep. This is in line with previous research (e.g. Di Millia & Kecklund, 2013) and substantiated by the sleep debt findings in the current study. Sleep debt (as measured with both a sleep log and actigraphy) was shown to be a strong predictor of fatigue as every additional percent of sleep debt increased the risk of critical fatigue by 8%. This highlights the importance of optimising the rest period in between duties, and thereby the duration and quality of sleep for ATCOs.

Non-roster related factors

When examining non-roster related factors, the following factors were shown to contribute the most to increasing ATCOs fatigue: monotonous traffic situations, high traffic complexity, difficult weather conditions, and coordination with colleagues and/or other ATC centres. These results are consistent with previous literature showing that both very low and workload levels may affect fatigue (e.g. Grech et al., 2019).

Validity of subjective fatigue ratings

The validity of the subjective fatigue ratings used was determined by means of a separate objective data collection campaign. A significant correlation between the percentage of eye closure as measured by means of eye tracking and subjective fatigue was found, for which it was concluded that the subjective fatigue ratings used in this study are valid measures for fatigue and sleepiness detection in ATCOs. Subjective fatigue was not found to be significantly correlated with performance, nor was subjective workload with eye tracking metrics. These findings underline that the different types of fatigue-related outcome measures (subjective, objective, performance based) should be seen as complementary measures, and that utilising multiple types of fatigue measures offers the most comprehensive understanding of the fatigue levels and performance capabilities of ATCOs. To be able to this, ATSPs, researchers and regulators should seek for practicable and valid (technological) solutions for fatigue monitoring and/or detection to be implemented alongside subjective fatigue ratings, as part of possible reactive FRM measures.

Considerations for fatigue assessment

Overall, the project has shown that several aspects should be considered by the ATSPs for the assessment of fatigue in their current operations:

- Considering the organisational and operational context is important to understand how fatigue factors impact ATCO fatigue and to identify appropriate mitigation measures.
- When evaluating ATCO rosters, it is important to combine expert analysis with the use of biomathematical models (BMMs), as these analyses appear to be complementary, and not to rely on BMMs alone.
- An important consideration is that individual factors may multiply and emphasise each other in a combined context. This accentuates the precaution that must be taken regarding risks that may compound one another.
- Understanding fatigue related factors in different operational settings should be part of the ATSP’s fatigue risk assessment and management. To that end, this study has identified some useful practices in terms of roster planning, fatigue risk management processes, the practical management of fatigue factors, and ATCO's education and awareness training, that could be considered by ATSPs.
- The findings also underlined that since different types of fatigue measurement methodologies can be seen as complementary to one another, it is important not to rely on self-reported ratings alone, and if possible measure fatigue and performance objectively as well.
- Implementing the currently available fatigue detection technologies and/or measures could be difficult for ATSPs, especially considering the time and labour involved. For real-time objective fatigue monitoring in the OPS room it is therefore interesting to look at future technological developments and the research associated with these.

The results obtained from this study provide a comprehensive assessment of the current situations in terms of fatigue risk exposure among the European ATSPs. They suggest a relatively low risk of fatigue as the ATSPs are already limiting the various roster parameter. They are also useful to support recommendations for EASA to mitigate fatigue risk during operations (see section 8.2). However, the study cannot define what would be an acceptable level of risk in terms of the percentage of duties with critical fatigue. Indeed, this cannot be supported by scientific findings alone as the determination of an “acceptable level” is a policy decision, influenced by current resources, operational constraints, scientific data, and overall safety risk exposure (including traffic level and complexity). Similarly, deriving (prescriptive) values for roster elements directly from scientific studies poses significant challenges.

The available evidence from this study’s data sample is currently not sufficient to support such policies: the body of existing scientific evidence is currently lacking, as this is a relatively new field of study, and nowhere near the decades of existing research around pilot fatigue. In the course of the study, some stakeholders referred to EASA Flight Time Limitations (FTL) when discussing the present ATCO fatigue study and roster limitations. However, the FTL had a different historical background and extensive pre-existing research in comparison to the current ATCO fatigue study, which was a first of its kind in Europe. Thus, the evidence developed in the current study has several areas that need to be supplemented or further explored in future research (section 8.3). This study is based on an observational methodology, meaning that data on existing practices were collected to assess fatigue risk. In such design, not all the variables can be controlled, and risk variations can be predicted to a certain extent, but it is not possible to extrapolate beyond certain values. Therefore, further research would be required to provide evidence on hard limits while controlling other factors (section 8.3).

Additionally, the variability in the ATCO positions and jobs across the industry is much larger than it is for aircrew. Job challenges differ vastly from one ATSP to the next and from one ATCO position to another within each ATSP, which makes it much more difficult to work with strict and specific limits.

Moreover, setting (prescriptive) limits is never solely based on evidence. Evidence and factual circumstances are only part of the equation, with various other factors coming into play as previously mentioned. The level of fatigue risk associated with certain hard limitations in roster elements is also not exclusively dependent on rostering elements, but also on other fatigue factors.

Part III: ATCO Fatigue Management in the Future

6. Good practices and guidance for ATCO fatigue management in the operational environment

6.1 Introduction

This chapter presents good practices and guidance to support EASA and concerned stakeholders in the management of fatigue risks in the operational environment, stemming from a combination of study results and expert knowledge within the consortium.

In parallel or in addition to potential prescriptive measures that the regulator could adopt (see section 5.5), the development and implementation of a Fatigue Risk Management System (FRMS), tailored to the specific operational environments, is an important and priority measure to systematically and comprehensively address ATCO fatigue. In addition, an effective FRMS is considered an enabler for effective prevention and mitigation measures for ATCO fatigue. However, reaching a full FRMS requires the progressive implementation of a number of processes and should be supported by a strong commitment from the ATSP management and the allocation of dedicated resources. For most service providers, acquiring a full FRMS will require at least several years, depending on the maturity level of FRM processes already in place.

A complete FRMS includes a policy and documentation, Fatigue Risk Management processes, Assurance processes and Training and Promotion activities. This chapter presents the study's recommendations in a way that clearly links to elements of the FRMS framework. A distinction is made between reactive, proactive and predictive fatigue risk management initiatives. The good practices and guidance presented in this chapter are in line with and complements ICAO document 9966 (ICAO, 2016). Compared to the ICAO document, it provides more details, based on the study results and specific to the EU situation, that can be adopted by EU ATSPs and ATCOs, based on study results and expertise within the study team.

Figure 6-1: Four elements of a FRMS that will be addressed in this chapter.

The recommendations are structured into different categories:

- Fatigue policy and documentation, and management commitment (section 6.2).
- Predictive fatigue risk management practices, covering recommendations and best practices related to rostering practices related to the eight mandatory roster elements (section 6.3.1), other rostering practices (section 6.3.2), and usage of biomathematical models (section 6.3.3).
- Proactive fatigue risk management practices, covering recommendations on subjective and objective measurements of ATCO fatigue (section 6.4.1) and surveys and focus groups (section 6.4.2), and concrete measures, not related to rostering, that are deemed most effective and applicable for ATSPs and ATCOs for the prevention and/or mitigation of ATCO fatigue (section 6.4.3).
- Reactive fatigue risk management practices, covering fatigue reporting (section 6.5.1), occurrence investigation process related to fatigue threats (section 0), and inducing a positive organisational culture and behaviour in ATSPs (section 6.5.3).
- FRMS assurance to assess the effectiveness of the mitigation measures (section 6.6).
- FRM promotion covering education and training of staff involved in rostering or fatigue management (section 6.7.1) and communication (6.7.2).

Further details of recommended practices for the management of ATCO fatigue in the operational environment and prevention and mitigation measures for ATCO fatigue can be found in Annex E and Annex F respectively. Future research activities to further increase the knowledge and scientific evidence on ATCO fatigue prevalence, causes and effects, and effective prevention and mitigation measures, are proposed in section 8.3.

6.2 Fatigue policy and management commitment

The FRMS policy reflects ATSP's commitment to managing the risks associated with fatigue in their operations. A definition of all the elements of the FRMS and the roles and responsibilities of those involved must be described in the FRMS policy, as well as tangible safety objectives. The FRMS policy implies a notion of shared responsibility between the ATSP management and ATCOs, and it is strongly recommended that the policy is signed by the executive in charge (accountable manager).

The FRMS documentation must include this FRMS policy, describing all the FRMS and safety assurance processes of the ATSP as detailed in Annex E.6. It should also establish a clear procedure in case an ATCO is unfit for duty due to fatigue (see Annex F.3 for more information). The documentation should define all FRMS activities and contain all the results of the analyses resulting from the data collection and other Fatigue Risk Management (FRM) actions that have been implemented by the ATSP. The mitigation measures resulting from the FRM activities must also be documented. Likewise, the history of changes made to the FRMS must be kept. The frequency of review or updates of the FRMS is dependent on the ATSP organisation, resources and local conditions. However, common practice is to review and update management system elements (e.g., policy, objectives, action plans etc.) on a yearly basis.

It is recommended that ATSPs establish a Fatigue Safety Action Group (FSAG) with the responsibility for coordinating all FRMS related activities. The principal functions of the FSAG are to oversee the development of the FRMS, to assist in its implementation, to supervise the ongoing collaborative operation of the FRMS processes, to contribute as appropriate to the safety assurance processes, to maintain the FRMS documentation, and to be responsible for ongoing FRMS training and promotion. The FSAG consists of representatives of all FRM stakeholders, while a single individual may represent more than one stakeholder group. The stakeholders could include the director of operations, planning and rostering staff, human resources representatives, safety representatives, and ATCOs or union representatives. To take part, the persons involved in the FSAG should receive an appropriate training (see section 6.7.1).

6.3 Predictive fatigue management practices

Predictive processes are designed to prevent fatigue threats when building ATCO rosters, by taking into account several fatigue factors that affect fatigue, sleep and performance. This section provides recommendations on the eight mandatory roster elements from the EU regulation (section 6.3.1), other rostering practices (section 6.3.2), and the use of biomathematical models (section 6.3.3).

6.3.1 Eight roster elements

The study observed large differences between the values used by the ATSPs for the eight roster elements. Table 6-1Table 6-1 shows the average maximum and minimum values, with standard deviation, for the roster elements based on the data collected from the 36 ATSPs. The table shows the data on the eight roster elements differentiated between ATS provided from an ACC and an aerodrome[23] for 2023.

[23] ATS provided from an ACC (ACC, sometimes including APP) and aerodrome control towers (sometimes including APP).

Table 6-1: Average maximum or minimum values and standard deviations for the eight roster elements, differentiated between ATSPs providing air traffic services at ACCs and aerodromes in 2023.

Roster elements	Area Control Centres (ACC)		Aerodromes (TWR)	
	Average	Standard deviation	Average	Standard deviation
(1) maximum consecutive working days with duty (days)	5.9	1.4	5.8	1.7
(2) maximum hours per duty period (hours)	9.2	3.0	10.5	2.7
(3) maximum time providing air traffic control service without breaks (minutes)	90	38	154	89
(4) ratio of duty periods to breaks when providing air traffic control service	0.69	0.10	0.72	0.10
(5) minimum duration of rest periods (hours)	11.6	5.3	12.0	5.1
(6) maximum consecutive duty periods encroaching the night-time (days)	2.3	1.0	2.9	1.2
(7) minimum rest period after a duty period encroaching the night-time (hours)	22.5	19.5	17.8	15.5
(8) minimum number of rest periods within a roster cycle	3.7	2.0	3.7	4.5

Based on the results from the data collection in six representative ATSPs, the averages values applied by the 36 ATSPs can be associated with a fairly low critical fatigue risk of around 5.6%. The current fatigue risk seems fairly low, but should not be considered as an absolute value, as it may vary depending under specific and local conditions. The above values therefore give a baseline which indicates an order of magnitude and which can therefore be used as a benchmark by ATSPs

The following parameters have been found to significantly increase the risk of critical fatigue levels. The study calculated a 'Fatigue risk index' for the main fatigue factors. Four of the eight mandatory elements of the regulation were identified as generating a potential risk of critical fatigue. The increase (or decrease, in case of negative values) of a parameter is compared to the baseline critical fatigue risk defined as the average value of each parameter[24].

- **Maximum consecutive working days with duty (days):** Every additional working day increases the risk of critical fatigue by 27%.
- **Maximum hours per duty period (hours):** Every additional hour per duty period increases the risk of critical fatigue by 10%.
- **Maximum time providing air traffic control service without breaks (minutes)**: Every additional 60 minute, within in one work session, increases the risk of critical fatigue by 33%.
- **Minimum rest period after a duty period encroaching the night-time (hours):** Each additional day of rest following a duty encroaching night-time reduces the risk of critical fatigue in the next duty by 43%.

[24] The baseline risk is defined as the 5.6% of risk of critical fatigue measured on the average values of the data sample presented in Table 2.1, p. 29. See also Table 5.6 p.53.

Figure 6-2: Three parameters have been found to significantly increase the risk of critical fatigue levels.

Setting values different from the baseline average values indicated in Table 6-1 would increase the risk of occurrence of critical fatigue, as illustrated in the following example:

<u>Example -Maximum consecutive working days with duty (days)</u>
The data collected in the study indicates that the EU ATSPs apply on average a maximum of 5,9 consecutive days for ATCOs employed at ACCs. This average corresponds to a level of 5.6% of critical fatigue risk. For every additional consecutive day added to this average, the critical fatigue risk **increases by 27%.** Thus, 7 days would represent 7% of critical fatigue risk (i.e., 27% of 5.6% in addition to the baseline 5.6% of critical fatigue risk), and 8 consecutive days would represent 9% of critical fatigue risk. 10 consecutive working days make the critical fatigue risk step up to 15%.

In the context of the implementation of an FRMS, ATSPs should be able to adjust these values according to their local constraints in terms of traffic density and complexity, as well as their resources and capacities. The approach developed the study can be used by the ATSPs to support their own assessment and develop their risk assessments with appropriate, and where necessary, increasing mitigation measures.

6.3.2 Other rostering parameters and working hours

Finally, Table 6-2 summarises guidance and recommendations from scientific studies existing prior to this study that were mentioned in previous chapters and which relate to other rostering parameters such as speed and rotation of duties, rest days, night shifts, etc. This guidance can help ATSPs in developing rosters and analysing rosters and objective and subjective fatigue data.

Table 6-2: Scientific guidance on rostering practices used for the roster analysis.

Roster elements	Scientific guidance
Consecutive duties	- Schedule consecutive duties to start later and later to allow better recovery between duties. - Compensate consecutive duties starting earlier and earlier by min. 2 rest days before and after.
Duty length	- Avoid long shifts on the first day of a working cycle. - Avoid long shifts after four consecutive working days. - Avoid long consecutive duties.
Night duties	- Avoid more than two consecutive night duties.
Rest after night duties	- After one night duty, schedule at least one night free of duty (i.e. no duty starting before 0900 local time). - After two or more duty, schedule at least two nights free of duty (i.e. no duty starting before 0900 local time). - No morning shift before the ATCO had 72 hours of rest.
Consecutive morning duties	- Max. 2 consecutive morning duties starting between 0400 and 0600 local time, or max. 3 if the start of the duty is at least one hour later than the previous duty. - Max. 3 consecutive morning duties starting between 0600 and 0900 local time - Max. 4 consecutive morning duties starting between 0400 and 0900 local time if each duty starts min. 1 hour later than the previous one
Direction and speed of rotation of duties	- Use “fast” rotations rather than “slow” rotations. - Use clockwise rotations rather than counter-clockwise rotations. - Limit transitions to one transition per cycle. - Limit the end of the first duty following a morning sequence to 2300 local time.
Rest days	- Avoid isolated rest days. - Gather rest days: rest periods should last for a minimum of 2 consecutive days. - Avoid scheduling an evening duty before a rest period. - Avoid scheduling a morning duty when resuming work after a rest period. - In the case of an isolated rest day, schedule a morning duty before and an afternoon duty after, to benefit from two complete nights free of duty.
General recommendations	- Avoid consecutive sequences of night or afternoon duties. - Avoid scheduling more than five consecutive duties, or allow for at least 54 hours of rest if six consecutive duties must be scheduled. - Maintain a minimum of two evenings off per week. - Avoid last-minute changes wherever possible. - Balance the workload as much as possible between the work duties of the same ATCO, but also between ATCOs.

The top-5 contributing fatigue factors for critical level of fatigue are shown in Figure 6-3.

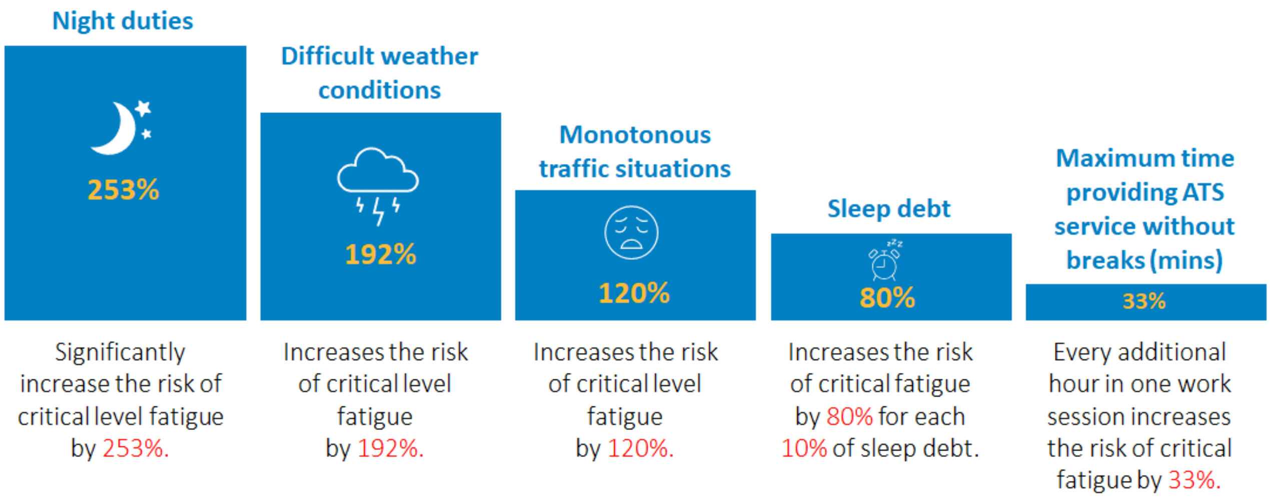


Figure 6-3: Top-5 fatigue contributing factors.

It is further advised to adopt harmonised measures to distinguish shift types within the boundaries defined in Figure 6-4. Using a data-driven approach in the subjective data collection, duty types were defined as presented in this figure (see section 5.3.2.2 for further explanation). The data analysis found that morning and night duties significantly increase the risk of critical fatigue in comparison to day duties. It is therefore crucial to implement separate mitigation measures regarding both these duty types.

Figure 6-4: Data-driven definition of duty types.

Regarding the definition of 'working hours', and based on the results of the data collection, differences were found in the fatigue effects of the accumulation of non-operational duties, such as office duties, simulator duties, medical checks, training duties, and other types of non-operational duties (which account for 20% of the studied duties). While in the present study no impact of the individual non-operational duties on fatigue levels were identified, fatigue levels were found to increase with every additional non-operational duty hour. It is therefore recommended that both operational and non-operational duties should be included in the working hours in order to account for the cumulative character of fatigue.

6.3.3 The usage of biomathematical models

A biomathematical model (BMM) predicts fatigue or alertness based on specific work schedules and the estimated amount of sleep. Most models consist of a software application into which the hours of scheduled work are entered. The model then produces an estimate of the level of fatigue, sleep, alertness and/or performance. ATSPs can use BMMs in the following five applications:

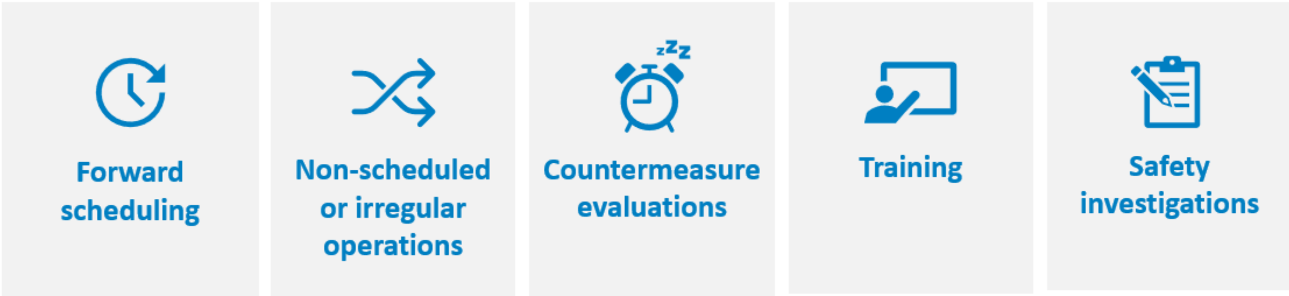


Figure 6-5: Potential applications of biomathematical models by ATSPs.

- **Forward scheduling**, with the capacity to compare the predicted results of proposed work schedules. BMMs allow the identification of vulnerabilities in the rosters through the evaluation of fatigue risk related to potential work schedules.
- **Non-scheduled or irregular operations**. In addition to forward scheduling, BMMs can also be used to assess the likelihood of fatigue associated with unplanned changes to operating requirements and original crew rosters (including tasking or position changes, shift swaps, and extension of duty hours).
- **Countermeasure evaluations**, such as the implementation of napping.
- **Training**. BMMs can be valuable tools to support fatigue risk training of rostering staff as they allow users to visualise changes in fatigue predictions through a dynamic user interface.
- **Safety investigation**, to assess the possible contribution to fatigue from the rostering system and investigate (lack of) sleep in a specific safety occurrence (see also section 0) and/or fatigue report. If the BMM analysis indicates that there is no fatigue risk in the concerned roster, there can still be fatigue resulting from other factors.

The use of BMMs before the execution of the rosters provides ATSPs the opportunity to assess the impact of a roster on the estimated experienced fatigue levels before a roster is executed. Per definition, as the predicted assessment of an expected fatigue level remains generic, BMMs cannot be used to determine whether an individual was or was not fatigued post duty. Furthermore, in many ATSPs, the rosters undergo several changes between their publication and actual execution (e.g. due to swapping between ATCOs). It is, therefore, important to use BMMs after any changes to the rosters as well, to ensure representative predictions of fatigue levels and allow the management to validate/approve the changes or not. These real-time assessments with BMMs allow for a more robust fatigue risk management, enabling ATSPs to quickly identify and mitigate fatigue risks that may arise due to roster changes.

When evaluating rosters, it is important to combine expert analysis with the use of any type of models, as they appear to be complementary, and not to rely on BMMs alone. While the BMMs help to objectify the results of the expert analysis by generating fatigue scores, the expert analysis also helps to refine and even clarify the results of the BMMs. The expert analysis addresses also other factors, the whole organisation of the rosters, the role of cumulative fatigue, and specific roster criteria (long period of duty, early shifts, rest time between two shifts, working hours over seven days, direction and speed of rotation, and rest days). This additional analysis thus helps to verify the potential risk generated by different shift types and/or rosters, as well as the role cumulative fatigue and other factors may play in fatigue prevalence.

It should be mentioned that BMMs have been designed to allow users to estimate the impact of hours of work on sleep and fatigue. They do not, however, constitute an FRMS on their own, but are only one of the tools that may be used by the ATSP within an FRMS. Indeed, in isolation, no single method of assessing fatigue is likely to be adequate. Good practices on the use of BMMs are detailed in Annex E.1.

6.4 Proactive fatigue management practices

Proactive processes are designed to identify fatigue threats by measuring fatigue levels in current operations and assessing their potential impact on safety, and to implement and assess the effectiveness of mitigation strategies. This section addresses recommendations on subjective and objective measurements of ATCO fatigue (section 6.4.1), surveys and focus groups (section 6.4.2), and practical measures to prevent and mitigate fatigue (section 6.4.3).

Figure 6-6: Proactive fatigue measurement practices.

6.4.1 Subjective and objective measurements of ATCO fatigue

Subjective and objective measurements of ATCO fatigue enable the ATSPs to collect data on ATCO fatigue in their operational practice and obtain insight into the level of fatigue and fatigue factors in their operations. The subjective and objective measurements can be applied during specific data collection periods, specific shifts, or on a continuous basis.

Subjective assessment of fatigue is based on the direct feedback from the ATCOs themselves. These subjective assessments should be collected by several means of validated scales. The two most commonly used and well-validated scales in aviation are the Samn-Perelli Fatigue Scale and the Karolinska Sleepiness Scale (both shown in Annex E.4). Applying these scales allows comparison of fatigue levels with other ATSPs and earlier published fatigue research. Moreover, the scales only have one item (question), are quite self-explanatory, can be applied on paper or electronically, and the cut-offs for critical fatigue are well known. In addition, airlines use the same scales for their fatigue reports and/or monitoring and in the present study, these subjective rating scales were shown to be able to measure ATCO fatigue in a valid way.

Fatigue data can also be collected using objective measurements techniques, such as continuous eye tracking. Utilising multiple fatigue measurement methodologies might give a better insight, while relying on subjective ratings alone may not offer a comprehensive understanding of an individual's fatigue levels and associated performance capabilities. However, implementing multiple fatigue detection methodologies or technologies may be difficult for ATSPs, especially considering the time and labour involved in setting up currently available eye tracking systems.

The level of cognitive performance during work could be derived from vigilance tasks such as the 3-minute PVT used in this study, but numerous other validated options exist (e.g. n-back task, Mackworth clock task, etc). An important consideration, however, should be that the execution of this task should not interfere with the normal activities of ATCOs.

In section 5.4.2, the challenges in using these advanced eye tracking systems in an operational environment were described. Most striking were the operational challenged involved with continuous measurements in the OPS rooms. Therefore, once validated, less intrusive and easier to set-up technologies (such as wireless EEG, speech analysis or web-cam based eye tracking) may be considered by ATSPs as an alternative.

The main currently available methods that can be used in the context of fatigue data collection are listed in Annex E.4.

6.4.2 Surveys and focus groups

In addition to measuring fatigue during actual duties, collecting data on ATCOs' general perception of their working environment, fatigue factors, health, and well-being can provide the ATSP with a global overview of fatigue threats and possible solutions. In this context, using a comprehensive approach that combines both quantitative and qualitative methods is recommended. For the quantitative approach an (online) survey for the ATCOs could be used. These surveys would enable the collection of a large amount of data across the ATCO population. In the context of fatigue management, surveys generally cover several topics such as:

- Demographic data (age, gender, experience, job position, commuting time).
- Sleep, health, and well-being questionnaires. It is strongly recommended to use standardized and well-validated questionnaires (e.g., the Epworth Sleepiness Scale, Pittsburgh Sleep Quality Index, etc.).
- Assessment of psychosocial conditions (at work). Examples of well-validated questionnaires are the Job Content Questionnaire (Karasek, 1998) or the Copenhagen Psychosocial Questionnaire (COPSOQ) (Pejtersen et al., 2010).
- Ratings and appraisal of different potential fatigue inducing factors (roster and non-roster related).
- Coping strategies to manage fatigue (napping, nutrition, use of caffeine, sport, etc.).
- Perception on how the organization is considering and managing fatigue.

The main advantage of (online) questionnaires is that they can provide a large amount of data in a relatively short time. They can also be administered regularly (e.g., every year), do not require the assistance by experts and involve low costs. Furthermore, questionnaires can be used to track trends in the levels of (chronic) fatigue, wellbeing and health of the target population. For quality and effectiveness purposes it is important to apply the following practices when using surveys:

- A comprehensive communication strategy to the ATCO population should be implemented to explain the main objectives of the survey, to explain data protection and privacy, and the benefits of participating, in order to maximize the participation rate.
- The use of standard and validated questionnaires is strongly recommended. In-house developed questionnaires might induce biases.
- As low participation rates might relate to selection biases, maximal participation of ATCOs in the survey is essential to ensure a representative sample. ATSP should make sure that as many ATCOs as possible participate in order to get a representative understanding of the problem.
- Once the data have been collected, the representativeness of the sample should be verified against demographic factors (age, gender, job position, etc.).
- Communication of the results should be transparent.

To complement online questionnaires, the use of a qualitative approach should also be considered. In this context, individual and/or collective interviews can be conducted with a sample of participants. This can include ATCOs, but also rostering staff, supervisors, ATSP management, etc. As ATCOs may be reluctant to share their views with their management, these interviews can be conducted by external facilitators provided that a confidentiality and anonymity agreement is put in place. These interviews have proven to be very useful in delving into specific topics identified in surveys. In most cases, the focus group method could be a relevant interview approach. Focus groups are collective interviews (between four to eight participants maximum) during which all attendees can express their thoughts, and react to each other's. In the context of fatigue management, the focus group could start with general questions on fatigue and related issues, and then progressively delve into more specific topics such as examples of problematic rosters, workload issues, workplace quality, rest facilities, etc.

The main limitation of questionnaires is that they could be influenced by other factors not related to fatigue. This is why it key to use combined approaches.

6.4.3 Non-rostering measures for preventing and mitigating ATCO fatigue

Within this study, a list of the most effective and practical non-roster-related means for the prevention and mitigation of ATCO fatigue, according to a representative panel of experts, was drawn up. The experts, with various backgrounds, reviewed and assessed the effectiveness and applicability of existing and new approaches to prevent and mitigate ATCO fatigue by means of a three-round online Delphi survey. A total of 31 fatigue mitigation and/or prevention measures was presented to the expert panel, and the experts were asked to independently indicate to what extent they found these measures effective for, and applicable to, European ATCOs and ATSPs. The participation rate of the experts was relatively high (≥70%). Annex F provides more information on the approach used for this part of the study, and the measures, participants and discussion regarding the measures[25].

Consensus was reached on the following six measures; they were deemed most effective and applicable for European ATSPs and ATCOs (the higher on the list, the more effective the measure was deemed). Note that rostering-related measures are excluded, because these were addressed in other parts of the study.

1. Implement or create an FRMS to structure mitigating measures.
2. Provide bedrooms near OPS room to allow ATCOs to sleep (before, during or after shift).
3. Provide quiet rest facilities near OPS room.
4. Introduce an educational programme about strategies to enhance adaptation to shift work (e.g. by means of light exposure, physical activity, nutrition)[26].
5. Promote pre-duty napping (e.g. before a night shift).
6. Promote napping during breaks. NB: For 'napping during breaks' evidence was found in the scientific literature as well.

The measure that is considered to be most effective is the implementation or creation of a full Fatigue Risk Management System, indicating that the experts expect that separate mitigation measures might not be enough to manage fatigue in ATCOs, but a more systematic and comprehensive approach is needed. This comprehensive approach involves a thorough fatigue data collection, fatigue data analysis, careful selection and implementation of interventions, followed by continuous monitoring of their effectiveness.

Furthermore, the majority of the measures deemed effective and applicable aim to improve the capacity of ATCOs to cope with irregular working hours, either by means of enhancing individual behaviour (due to napping, physical activity, caffeine), or by means of coaching (lifestyle, sleep, stress). These topics could become part of the (standard) education and training of ATCOs, so that ATCOs learn how to apply this in their daily life either at work or at home).

It should be considered that there is no 'one size fits all' approach to the prevention and mitigation of ATCO fatigue. While considering these (and other) measures as intervention candidates, it is important that ATSPs consider while taking into account the specific culture within their organisation, the needs and wishes of the target population, and the individual characteristics of the ATCOs, in order to gain their support. Next, the ATCOs hold a responsibility to apply and make us of these measures for them to be as fit for duty as possible.

Finally, it should be acknowledged that for most of the measures, additional experimental scientific studies are needed to prove their effectiveness. The evidence for their effectiveness (besides napping) in ATCOs is still scarce. ATSPs should consider this when implementing these fatigue-related activities. As part of the implementation, ATSP are recommended to develop assurance activities and closely monitor the effects and effectiveness and thereby build up evidence.

6.5 Reactive fatigue management practices

Reactive processes are designed to identify the contribution of ATCO fatigue to safety reports and occurrences in order to identify how the effects of fatigue could have been mitigated or minimised and to reduce the likelihood of fatigue threats and similar occurrences in the future. This section addresses recommendations on fatigue reporting (section 6.5.1), occurrence investigation process related to fatigue threats (section 0), and inducing a positive organisational culture and fatigue reporting behaviour in ATSPs (section 6.5.3). More

[25] For further information on the approach, details of the analysis and results, refer to the study deliverable D-2.E.

[26] Regulation 2015/340 makes it mandatory to provide a training programme, including fatigue, but does not contain specific topics.

information on these reactive practices can also be found in the ICAO Doc 9966 “Manual for the Oversight of Fatigue Management Approaches” (ICAO, 2016).

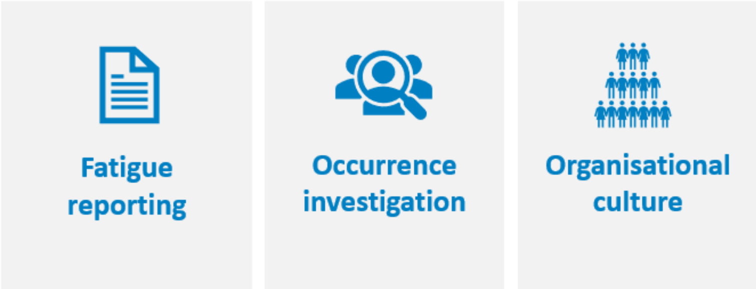


Figure 6-7: Three topics will be addressed in this part of the report under reactive fatigue management processes.

6.5.1 Fatigue reporting

The regulatory requirement on fatigue reporting is overall well implemented by the EU ATSPs. However, in this study, indications were found that the fatigue reporting mechanisms are not fully effective. The following recommendations support ATSPs and ATCOs in improving the quality and effectiveness of the fatigue reporting mechanisms.

As stated in the ICAO Doc 9966 (ICAO, 2016) two kinds of reports are concerned: mandatory reports and voluntary reports. Mandatory reports refer to occurrences that should always be reported because they have been considered by the regulator as posing a significant risk for aviation safety. Voluntary reports are reports of events or hazards that may be reported if deemed relevant by potential reporters involved in aviation activities. Several factors could influence the reporting culture and quality of reports and results obtained, such as the safety culture, social climate, knowledge and understanding of the reporting system, and lack of feedback to reports by the organisation. If the reporting system used by an organisation does not have a clear policy, is confusing or difficult to use, or if employees are not properly trained on how to report incidents, underreporting may occur. It is therefore important to have regular bottom-up and top-down communication adapted to the target audience. In addition, ATSPs are advised to communicate to the ATCOs that their report has been received, and, subsequently, to give feedback on the actions taken following their report. Apart from this individual follow-up, ATSPs can also communicate trend analysis and aggregate results from ATCO fatigue-related occurrences and fatigue reports to all ATCOs.

The ATCO submitting a fatigue report must be made aware of how their information is used after it is received by the ATSP. It must be clear what will happen to the information, when this will happen, and how the ATCO will be treated as a result of filing a report. The fatigue report information should be provided to the FSAG confidentially.

The vast majority of the ATSPs (88%) that responded to the survey had established a dedicated fatigue reporting mechanism. When a dedicated system was not in place, the occurrences could be reported through the standard mechanism of Regulation (EU) 376/2014. Based on the findings of the present study regarding the use and effectiveness of the reporting systems (see Chapter 2 and 4), it is recommended to use specific reporting forms for fatigue to identify the causes and effects of fatigue in relation to an occurrence or in fatigue reports not necessarily linked to an occurrence. The type of information that should be collected in a fatigue report form in order to assess fatigue in an optimal way is:

- A section related to the ATCO: preferably the name of the individual (but anonymous reporting should also be possible), ATCO position, contact number, unit, manager and date of the report.
- A section for contextual information: detailing the context or circumstances of the occurrence, date and time of the occurrence, incident reference number, and duty time details (e.g. start and end time).
- An open text section to enable the ATCO to provide details of the occurrence or the safety concern in an open text format (i.e. the narrative).
- A multiple choice section with items concerning the potential causes of the fatigue, including roster- and non-roster related factors.

- A multiple choice section with items concerning potential fatigue and sleepiness symptoms which were felt or observed prior to or at the time of the occurrence. The usage of validated fatigue rating scale (see Annex E.4) can be considered as well, to get insight into the experienced level of fatigue (if a fatigue and/or workload rating scale is included, ATCOs need to be trained on how to use these).
- An open text section to enable the ATCO to describe activities that were undertaken at the time of the occurrence (i.e., the narrative).
- A section to indicate, if known, the (approximate) amount of sleep obtained during the 24 and 48 hours prior to the occurrence.
- A section to indicate how long the ATCO had been awake prior to the occurrence.
- A final open text section, to provide any additional information that the reporter deems relevant.

Additional best practices for fatigue reporting are detailed in Annex E.3. Section 6.5.3 covers organisational culture incentivising fatigue reporting.

6.5.2 Occurrence investigation

As part of the occurrence investigation process, ATSPs should systematically identify and assess fatigue and potential fatigue factors as a causal or contributing factor to the occurrence. In particular, the following aspects have to be investigated:

- The level of fatigue, any potential causes or contributing factors to the level of fatigue, and the observed effects.
- The particular actions or decisions that the ATCO was taking prior and during the occurrence.
- The extent to which these actions or decisions are consistent with the type of behaviour that can be expected of a fatigued person.

A step-by-step approach to identify any potential contribution of fatigue to a safety occurrence is provided in Annex E.2. Best practices for safety occurrence reporting in relation to fatigue are detailed in Annex E.3.

6.5.3 Inducing a positive organisational culture and behaviour in ATSPs

During the assessment of the state of implementation of the EU ATCO fatigue regulatory requirements and their impact on affected stakeholders in the EASA Member States (see Chapter 2), some ATCO associations expressed their concern about the effectiveness of the fatigue reporting mechanisms and the ATCO fatigue information programmes. One interviewed ATSP indicated that in general ATCOs are not afraid to raise safety issues, but that maybe not all ATCOs are comfortable to report personal issues, such as fatigue. Another ATSP highlighted in the interview that a lack of reports does not necessarily mean a lack of fatigue among the ATCOs. Five ATCO associations stated that the current fatigue reporting mechanism is not effective and that this results in a low number of reports.

The ATSPs suggested to implement a good framework with emphasis on fatigue as an issue, which is not reduced by rostering as the only solution. They also suggested to look at possibilities to tackle fatigue from different perspectives, such as by offering guidance, consultation or nurturing the safety culture in order to allow for honest reports of fatigue without disciplinary consequences.

A fatigue reporting system can only be effective if ATCOs are informed of and know how to use the fatigue reporting system. The interfaces of the fatigue reporting system should be well-designed for ease of use and ATCOs should be familiar with it. Timely feedback on the follow-up actions and trend analysis arising from inputs to the fatigue reporting system should be provided to give assurance that safety concerns raised have been taken seriously by the organisation.

Processes, procedures and policies should be implemented to ensure the integrity of the fatigue reporting and to prevent its misuse. These processes should include timelines for feedback and assignment of reviewers for reports. They should also ensure that the information provided is used to improve safety and not to discipline individuals that filed the report.

Misuse of the fatigue reporting system to penalise or find faults with individuals will deteriorate the trust within an organisation, and this hinders the open sharing and reporting of issues related to fatigue. To mitigate potential misuse, the system must be confidential, but not anonymous. Secondly, a separate system can be set up in which employment conditions issues, including complaints, can be reported. This means that the content of fatigue and safety reporting systems remains clearer and better defined.

A fatigue reporting system can only function effectively when employees understand the purpose, capabilities, and consequences of making the fatigue reports, and adhere to its guidelines when making the fatigue reports. Organisations that have an incident reporting system and a separate fatigue reporting system should provide clear guidelines on when to use which system and provide information on how the information from both reporting systems is used. These guidelines could be made part of the information programmes on the prevention of fatigue that are required according to Regulation (EU) 2017/373. In addition, information about reports received through the fatigue reporting system and the corresponding actions taken as a result of these reports should be periodically communicated.

6.6 FRMS assurance

FRMS assurance includes monitoring fatigue risk management performance, assessing the effectiveness of fatigue risk management measures and assessing the effectiveness of the FRMS to ensure that the FRMS is operating as desired and to determine the extent to which fatigue management objectives are being achieved. The aim of this pillar of the FRMS is to ensure that the FRMS works and achieves its objectives:

- Maintain fatigue risk at an acceptable level.
- Adapt to changes in the operating environment.
- Allow continuous improvement of FRM processes.

In the context of fatigue management, ATSPs are advised to develop their own soft rules within their rostering practices, as well as control the applicability and effectiveness thereof in order to mitigate fatigue risk.

ATSPs are invited to follow the best practices outlined in ICAO Doc 9966. Accordingly, they should identify and monitor FRMS Key Performance Indicators (KPI) and considers changes to its operating environment and any impacts these changes may have on fatigue risks (i.e. conducing a Management of Change process). KPIs enable the ATSP to monitor the functioning of the FRMS processes and the effectiveness of fatigue mitigation and prevention measures. Data collected and monitored in the FRM processes can be used to define and quantify KPIs.

Indicators can be quantitative or qualitative:

- Quantitative: measures a number or a ratio, for example the number of fatigue reports or ATCO fatigue-related occurrences per year or per movement.
- Qualitative: measures a quality, is descriptive, for example the maturity of the FRMS.

A distinction is also made between process indicators (also called leading indicators in the literature) and outcome indicators (also called lagging indicators in the literature).

- Process indicators are oriented to a process or activity and usually refer to positive developments that an organisation wants to improve or strengthen, such as activities that enhance fatigue management. Examples are the number of FSAG meetings per year, the percentage of completion of corrective action plans, number of fatigue awareness campaigns or surveys.
- Outcome indicators are oriented towards an outcome and usually refer to negative outcomes or consequences that an organisation wants to avoid. Examples of KPIs are the number and frequency of fatigue reports, ATCO fatigue-related occurrences, fatigue causes or fatigue-related absenteeism, prevalence of average level of fatigue and high levels of fatigue These indicators can be normalised per duty type, duty hours, ATCO, traffic complexity, movements etc.

The KPIs may help identify ineffective measures. In that case, a detailed fatigue risk assessment of the issue should be conducted, in line with the ATSP's processes, and new or revised mitigations may be proposed where necessary. Internal audits and investigations are an additional means of ensuring that the FRMS is working properly. It may include a review of the results of the FRMS carried out by an independent panel of experts. External review/approval/oversight by a competent authority, as is done for airlines' FRMS, is also a possible option.

6.7 FRMS promotion

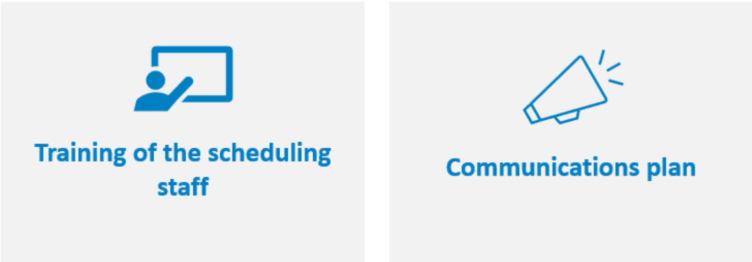


Figure 6-8: Training of scheduling staff and communications plan are part of FRMS promotion.

6.7.1 Training of the scheduling staff on fatigue risk management

It is recommended for ATSPs to organise a training programme for predictive FRM tailored to the ATSP's FRM managers, the staff in charge of fatigue report analysis, the scheduling staff, and Human Resource managers. The primary objective of such comprehensive training is to instil an understanding of the scientific principles related to sleep and fatigue, to familiarise the participants with the foundations of FRM, to educate on good rostering practices, to introduce scientific approaches to data analysis, and to raise awareness about the tools available and their inherent limitations. The training course should be based on the latest scientific knowledge, including best practices from other organisations in similar industries, and encompass both initial and recurrent modules. The recurrent training could be designed to be more 'lightweight', ensuring a continuous reinforcement of essential skills based on the participants' experience. To maintain sufficient organisational awareness, it is recommended to deliver a yearly recurrent training. The training curriculum should be structured to cover theoretical foundations, as well as tools and practical applications. The training content may include a spectrum of topics as described in Annex E . A recommended approach to the validation of fatigue-related training and education is described in Annex E .

6.7.2 Communication plan

Promotion is an essential pillar in the efficiency of an FRMS which relies very much on the participation of the ATCOs in the data collection or in the fatigue reporting. To foster this participation, the communication plan should include regular bottom-up and top-down communication tailored to the target audience. It should provide regular updates on the initiatives and decisions made on any topics related to fatigue management. To maintain a high level of fatigue reporting, it is key to communicate on how the reports are being processed and followed up.

7. Potential impact of future ATCO supporting technology on ATCO workload and fatigue

7.1 Introduction

The objective of this part of the study was to assess the impact of current and future ATCO supporting technologies on ATCO workload and fatigue. To ensure ATCOs are able to execute their demanding tasks well, they are carefully selected, thoroughly educated, continuously trained, and are supported by various technologies during their operational tasks. Supporting technologies are designed to support the ATCO by covering a wide range of ATCO tasks, from traffic surveillance to strategic decision making, and can therefore impact an ATCOs workload and task demand. In turn, this may affect ATCO fatigue and performance. In this task, the influence of current ATCO supporting technologies on workload and fatigue are assessed. The intended effect of a technology on workload as well as the effect of the technology in operational practice are considered.

In the field of ATCO supporting technology, significant developments are foreseen, such as a push for digitalisation and the rise of artificial intelligence. New specific ATCO supporting technologies will be designed and new operational concepts will emerge too. While these new technologies may potentially take over several ATC tasks, the role of the ATCO will remain crucial, albeit with a likely shift in tasks and a new balance between human and automated tasks. These changes are expected to have an impact on ATCO workload and fatigue in the future as well Hence, the objective of this task was to assess the potential influence of new and future operational concepts and technologies on ATCO workload and fatigue as well. The impact of current technologies was assessed in section 5.3, and this chapter provides an assessment of how future operational concepts and technologies can influence ATCOs workload and fatigue. This assessment excluded other types of impacts (e.g. capacity, environment, efficiency).

Various methods for assessing the impact of future ATCO supporting technologies on ATCO workload and fatigue were applied in this study, including:

- Review of existing literature, including research related to workload modelling and workload models, fatigue, and the relationship between workload and fatigue.
- Application of five methods to assess impact of technology support on cognitive tasks, ATCO workload, fatigue, namely a direct approach, analysis of expert opinion, human-in-the-loop experiments, and a model-based approach.
- Survey to collect inputs from ATSPs in the EASA Member States (36 ATSPs responded, a 78% response rate), including questions related to technology.
- A workshop was organised on the impact of (future) technologies on ATCO workload and fatigue. The workshop was attended by representatives from SESAR 3 JU, EASA, ATSPs, ATCO associations, and ATM industry. The workshop brought together a multidisciplinary group of experts, representing complementary knowledge, who provided multi-faceted insights and knowledge ensuring that the study team received inputs from different perspectives. The expertise, experience and knowledge available in the group of attendees included human factors, cognitive psychology, operational air traffic control, ATC research, ATC supporting technologies, fatigue, rostering and regulations.
- Inputs from the respondents to the survey that was distributed to the workshop invitees After the workshop, an online survey was distributed among the invitees to collect expert opinion and explanations on the impact of (future) technology. In total 26 respondents completed the questionnaire (out of 66 invited).

More details on the approach and results can be found in the study deliverables D-3.A and D-3.B.

7.2 Results

7.2.1 Added value of future ATCO supporting technologies for ATCO workload and fatigue

Technological integration and automation have the potential to reduce ATCO workload and alleviate fatigue. While current ATCO supporting technologies have already shown to benefit ATCOs, future technologies may add further value. The SESAR catalogue of technologies and concepts (SESAR Joint Undertaking, 2021) provides a set of 182 solutions, including 102 solutions expected to be available on the medium term (within five to ten years and with a Technology Readiness Level (TRL) 6). Some of these solutions may have a direct effect on ATCO workload and fatigue.

The general (holistic) assessment of this study is that a particular set of technologies may reduce workload and as a result alleviate fatigue. This is already the case for ATCO supporting technologies that are currently in use, but the development of new ATCO supporting technologies may result in further reductions in workload. Since a high workload over time might contribute to fatigue, the technologies that reduce workload can also help to reduce fatigue. In Annex G and study deliverable D-3.A more information can be found about the relation between technology, workload and fatigue. The results of this section are meant for future ATCO supporting technologies, yet they may also apply to current technologies already, perhaps to a lesser extent.

The study provided a list of technologies that are expected to help alleviate workload and as a result reduce fatigue (see study deliverable D-3.A). The list of technologies that may alleviate workload were based on following criteria:

- The technology has reached maturity level TRL 6 or higher;
- The technology has the potential to reduce traffic complexity;
- The technology automates tasks;
- The technology facilitates looking further ahead in time.

A relative important contributing factor to ATCO workload and fatigue is high traffic complexity (section 5.3), which could be mitigated with technology and automation support. The most effective way to reduce the impact of this factor by technology is by optimising traffic flows. Within that subset, the most effective means and tools seem to be:

- Route planner;
- Arrival manager;
- Departure manager;
- SID/STAR/runway allocation;
- Traffic (load) smoother;
- SWIM and (dynamic) sector management.

This is by no means an exhaustive list and traffic complexity is not the only factor for fatigue. New supporting technologies are likely to have objectives that extend beyond reducing ATCO workload and fatigue. Their impact will largely depend on the ATSP-specific implementation and integration with existing technologies and operations.

While the listed technologies may reduce the workload during traffic peaks or complex situations, they could increase monotony and introduce low workload or underload during off-peaks, which might lead to drowsiness (see next section).

The extent to which each of these technology reduces workload and possibly fatigue is wholly dependent on the specific ATCO position in a specific operational environment, considering the specific conditions of the ATSP. It is not feasible to unanimously quantify the impact of technology on workload and fatigue in general terms and it is not feasible to quantify the added value of the listed technologies in terms of a percentage-change of workload or fatigue that may be expected, even when conducting additional experimental research, notably through simulations. Though additional research may be beneficial, the impact is indeed very much dependent upon the local operational conditions. However, it is possible at each ATSP to apply a human centric approach and assess the impact and effect on ATCO workload and fatigue for a specific ATCO position for given operational conditions, etc. Such an approach would involve assessing workload for a specific ATCO position first, before conducting a Human Performance Assessment (HPA) and identifying and selecting specific technologies. Then, it is recommended to conduct human-in-the-loop experiments, and to analyse and balance the automation versus the role of the ATCO. Finally, the effectiveness should be continuously monitored (refer to Annex G for a more detailed approach). It is remarked that other factors impact ATCO fatigue as well, such as working hours, working conditions, sleep and recovery and the worker's capacity and these should be considered equally. Moreover, the reduction of workload that could be achieved in the operational practice due to technical advancements may be offset by traffic load increase and workload management strategies of ATSPs, also according to expert opinion expressed in the workshop and survey results.

7.2.2 Potential threats of ATCO supporting technologies for ATCO workload and fatigue

Next to benefits, as mentioned in the previous section, future technologies also bring potential hazards for ATCO workload and fatigue. This section describes several hazards related to (future) technology which may have a negative impact on ATCO workload and fatigue and can lead to fatigue risks for the ATCO. Based on literature review, experts opinion, the results from the workshop (breakout session and survey after the workshop), the following fatigue hazards related to technology have been identified: Potential for loss of sense of control, a shift in ATCO task distribution, monotonous situations and low work load/underload situations, and finally drowsiness.

7.2.2.1 Loss of sense of control

ATCOs may experience the out-of-the-loop phenomenon due to technological support, leading them to become less engaged, less aware or less responsive, and less actively involved in handling air traffic. However, such a hazard could be considered in the design phase in the sense that it is possible to adapt the automation in such a way that it ensures that the ATCO is never too busy or too idle.

In the SESAR definition phase, the concept of operation was based on strategic deconfliction of aircraft trajectories, such that the ATCO would only intervene by exception. However, after several years of research and after having consulted many stakeholders, the SESAR evolution went into another direction, such that tactical interventions with the system by the ATCO must now routinely be expected in the future ATC operations (see study deliverable D-3.B).

7.2.2.2 Shift in ATCO task distribution

Another potential risk of the technological development relates to a shift of the distribution of ATCO tasks, which in turn may negatively affect ATCO workload and fatigue. Four cognitive processes can be distinguished: Information acquisition & exchange, information analysis, decision & action selection and action implementation (study deliverable D-3.A). The distribution of the task execution over these cognitive sub-tasks may change significantly as a result of future technologies (as it for example certainly would if the ATCO only intervenes by exception, as discussed in the previous paragraph). It has been tried by the research team to identify such a shift in ATCO tasks for each of the ATCO roles of the assessment framework by analysing the relevant SESAR solutions available on the medium term. It was concluded from this exercise that for each ATCO role there are indeed several technologies that affect the ATCO tasks, but that there is no clearly distinguishable tendency towards one or more of the four cognitive processes. The effects also depend on the precise implementations, the effects of how several future technologies interact with each other and with current technologies, and on how the workload is managed by several means including individual coping strategies. This means that also the relationship between the distribution over ATCO cognitive sub-tasks and fatigue is not clear and might depend on the circumstances and the individual ATCO. The risk of the shift in ATCO task distribution might however exist and was therefore also put on the agenda of the workshop on future technologies. A shift in task distribution may have extensive effects on the ATCO, though it first should be noted that these effects may vary depending on the ATSP, the ATCO and the (temporary) operational situation of the ATCO. Regardless, a shift in task distribution may lead to:

- Cognitive overload, if tasks are redistributed when the ATCO does not have sufficient cognitive capacity;

- A loss of Situation Awareness (SA), if the automation would result in a rapid redistribution of tasks;
- Skill degradation, if the shift in task distribution leads to an ATCO not using a specific set of skills for a prolonged period of time, which may even especially show in non-nominal situations.
- Complacency, if the automation would systematically redistribute tasks in a specific way and an ATCO would experience overreliance on that specific redistribution, resisting any other task distributions. This may even result in a dependency on technology
- Fatigue and stress, if the task distribution is uneven, for example due to differences in traffic density, complexity of airspace or individual capabilities.

7.2.2.3 Monotonous situations and low work load/underload situations

ATCO supporting technologies should be designed in such a way that it does not disengage the ATCO too much because monotony is a fatigue threat. If workload is reduced too much in certain conditions it may actually increase (passive) fatigue, especially at night (Desmond & Hancock, 2001). It may also result in decreased alertness and arousal, which has a negative effect on ATCO performance (Vink, 2023). Specifically, ATCOs may have lapses in attention, increased reaction times when responding to unexpected events or even emergencies or communicating with other parties involved, and decreased vigilance when they are monitoring traffic. This is especially relevant at night when traffic volume tends to be low. Moreover, such decreased vigilance may result in the ATCO losing their situational awareness as ATCOs become disengaged from their surroundings. When ATCOs then do need to (quickly) shift from a low-workload to a high-workload situation, for example in the event of a non-nominal situation, ATCOs may find it challenging to shift to a heightened state of alertness (Moroney et al, 1995). They may need additional time to regain their situation awareness and take appropriate actions.

7.2.2.4 Drowsiness

In this study, both workshop participants and survey respondents argued that drowsiness is one of the major concerns in the implementation of new technologies, and that its likelihood increases especially with low workload, a reduced sense of control and an increase in routine tasks (study deliverable D-3.B). Drowsiness may arise after a period of low workload, unmasking underlying fatigue. As the two topics, low workload and drowsiness, tend to be related, many of the effects are also similar. These include reduced alertness, impaired decision-making, slow reaction times and decreased situational awareness. However, severe drowsiness can also lead to the ATCO experiencing microsleeps: These are defined as unexpected brief episodes of sleep which last between 1 to 30 seconds and occur during wakeful activities (Moore-Ede et al., 2004). Finally, drowsiness is closely linked to one's circadian rhythm, the body's internal clock. For ATCOs, the nature of their roster exposes them to circadian rhythm disruptions, especially during night shifts. Both the ATCOs' internal clocks, which would promote sleep during the night, and the low level of light exposure would make it more likely for an ATCO to experience drowsiness during a night shift. Therefore, the potential for drowsiness should be considered closely with the implementation of new ATCO supporting technologies, potentially making it adaptable to time of day.

7.3 Conclusions on the potential impact of future ATCO supporting technologies

The implementation of future ATCO supporting technologies can bring benefits to the ATCO by alleviating their workload, facilitating their tasks and therefore reducing their fatigue levels. These benefits can be assessed at local level, by applying a human centric approach (see Annex G) to assess the potential impact of a particular ATCO supporting technology on ATCO workload and fatigue for a specific ATCO position, in the local operational environment, including the circumstances, procedures, interfaces, weather conditions, etc.

However, future technologies also bring potential workload and fatigue threats which should be addressed in the development and implementation phase of technology. Based on literature review, expert opinion, the results from the workshop (breakout session and survey after the workshop), the following fatigue threats are deemed relevant: Loss of sense of control, shift in ATCO task distribution, monotonous situations and low work load/underload situations, and drowsiness. In particular, drowsiness and sleepiness due to combinations of low task load, high monotony in task execution, limited sense of control and working during the night are relevant.

As part of the study, recommendations have been defined in Chapter 7 to leverage the benefits of (future) ATCO supporting technologies and concepts, while preventing and mitigating their threats related to ATCO fatigue. The recommendations address in fact EASA, ATSPs, ATM industry, the Research and Development (R&D) community[27] because technology design, development, evaluation and implementation usually involves the collaboration of these stakeholders. The recommendations cover the following themes:

- Good practices to utilize the potential of (future) technology for the ATCO working position and the broader ATC environment to alleviate workload and possibly reduce fatigue.
- Good practices to ensure that ATCO fatigue threats resulting from working with (future) ATCO supporting technology are adequately addressed as part of the design, development and implementation phases (see Annex G).

Finally, in Annex G, the report provides guidance and good practices for ATSPs, ATM industry and Research & Development on conducting a human-centric approach to assess and mitigate fatigue threats as a result of (future) technology for a specific ATCO position and the local operational conditions. The purpose of the guidance is to consider systematically and appropriately ATCO workload and fatigue in the design, development and implementation of (future) ATCO supporting technologies. As part of the described human-centric approach, the report outlines good practices for conducting a Human Performance Assessment (HPA) including a Human-In-The-Loop (HITL) experiment for addressing ATCO fatigue threats of future technology (see study deliverable D-3.A for further explanations).

[27] Includes academia (universities, research institutes etc.) and SESAR 3 JU.

8. Main conclusions and key recommendations

8.1 Main conclusions

The present study established a comprehensive overview of ATCO fatigue in the EU by means of a literature review, an analysis of relevant safety data and a field study into ATCO fatigue and specific contributing factors. In addition, current working practises related to fatigue management and rostering systems in European ATSPs have been identified, and best practices and means for prevention and mitigation of ATCO fatigue have been established. The outcomes of these research activities yield the following conclusions:

1. Successful implementation of the ATCO fatigue regulations since 2017

The present study found that by 2023, the EU Regulations on ATCO fatigue have been successfully implemented across 46 ATSPs in the EASA Member States. No significant difficulties have been observed in their implementation. Compared to the situation before the adoption of the ATCO fatigue provisions, the analysis of available data indicated that there the situation has positively evolved between 2017 and 2023. In 2023:

- All non-conformities from EASA standardisation inspections related to this topic have been closed.
- 100% of the ATSPs have implemented an ATCO fatigue management policy.
- 88% of the ATSPs have a dedicated fatigue reporting mechanism, while 12% of the ATSPs report through the standard occurrence reporting system under Regulation (EU) 376/2014.
- 100% of the ATSPs declare that they assess fatigue as a potential contributing factor in occurrence investigations and analysis.
- 100% of the ATSPs have procedures in place for the identification and management of the effect of fatigue on operations safety, with 40% of the ATSPs collecting sleep or fatigue data on a quarterly or yearly basis.
- 88% of the ATSPs have included a specific module on fatigue in ATCO training, while 12% of the ATSPs are meeting this requirement only partially.
- 100% of the ATSPs have an information programme for ATCOs on the prevention and effect of fatigue.

While the requirements appear to be fulfilled, the ATCO representatives stressed that these measures are often either insufficient or ineffective in practice.

Regarding the rostering systems, average values applied by the EU ATSPs on the eight mandatory roster elements have been collected and show the following trends:

- Overall, a potential improvement in several roster elements was observed in 2023 compared to 2017 for ATCOs. The average maximum time providing air traffic control service without breaks has slightly decreased since 2017 for ATCOs at ACCs.
- There is a difference in average maximum time providing air traffic control service without breaks between ATCOs at ACCs and those at TWR, with the later having slightly longer working hours. This difference may be explained by the nature of the tasks or operational conditions, but this was not further analysed as part of this study.
- There are large variations on some of the elements, notably the minimum hours per duty period, the minimum duration of rest periods and minimum rest periods after a duty period encroaching the night time.

This lack of level-playing field can be explained by local conditions which differ from one country and one ATSP from another. Flexibility needs, ATCOs personal factors, specific national requirements (labour law) and traffic volumes are the main factors influencing the rostering.

Study results show that deviations from the planned roster regularly happen at the initiative of the ATSP, to take into account specific or unforeseen operational situation. Other changes, initiated by the ATCOs, e.g. swapping shifts, are sometimes made without systematic monitoring by the ATSPs. Some ATSPs however allow changes to the rosters after publication, only through a software that automatically checks that the rostering standards are still adhered to.

It appeared that this implementation was achieved without any strong social resistance. Surveyed ATSPs and ATCO associations noted a smooth implementation of the regulatory requirements, and confirmed that the implementation had no impact on the lifestyle or well-being of ATCOs.

The ATCO fatigue regulatory requirements have helped to achieve a more homogenous framework for the prevention and mitigation of ATCO fatigue. However, from the study it appeared that there are qualitative differences in the way that the ATSPs have implemented the ATCO fatigue regulatory requirements. Moreover, the study highlighted that the fatigue reporting mechanisms and training/information programs are not fully effective. Regarding the rostering systems, differences appeared between the values used by the ATSPs for the eight roster elements defined in the Regulation 2017/373. The values of the eight roster elements are determined by national regulations and by local conditions and practices and are, therefore, not identical across the EASA Member States. Guidance to achieve a better level-playing field on work and rostering practices could be considered for the future.

Uncertain safety impact as a result of ATCO fatigue provisions

The ATCO fatigue regulatory requirements have raised awareness of fatigue in general and on the reporting of ATCO fatigue in particular. Since the implementation of the ATCO fatigue regulatory requirements, the annual number of reported occurrences slightly increased but this cannot not provide conclusive quantitative evidence regarding the effect on safety. No ATCO fatigue-related accidents or serious incidents have been reported in the last ten years (2013-2022) in the EASA Member States (incl. the UK until 2020). Data from the European Central Repository (ECR) on ATCO fatigue-related occurrences was analysed, and only 184 incidents related to ATCO fatigue were found between 2013 and 2022. This indicates that the likelihood of ATCO fatigue-related occurrences is low.

However, some deficiencies were observed regarding the use of the ECR. The data lacked good quality of reporting and completeness. In addition, biases in reporting were evident. In the present study, these issues limited the detailed (statistical) analyses and affected the usability and statistical validity of the safety data analysis results. It cannot be ascertained that the results represent all EASA Member States.

Implementation of ATCO fatigue regulatory requirements had a limited economic impact

The implementation of the ATCO fatigue regulatory requirements had a limited economic impact. The total costs for the ATSPs in the 2020 - 2022 period were estimated at €16 million, and an estimated 30 additional ATCOs were recruited across EASA Member States to comply with the ATCO fatigue regulatory requirements. The majority of NSAs responding to the survey reported that the ATCO fatigue regulatory requirements did not impact their organisation, while all responding NSAs reported no direct change to workforce numbers as a result of the ATCO fatigue regulatory requirements. Due to a lack of quantitative evidence regarding the effect on safety, the costs of the ATCO fatigue regulatory requirements could not be compared against the safety benefits.

2. Insufficient detailed information on occurrences related to ATCO fatigue

Both the findings of the review of the scientific literature and the review of ATCO fatigue-related occurrences confirmed that at the moment there is not enough data to determine an association between ATCO fatigue and errors or incidents. The analysis of ATCO fatigue-related occurrences provided some insight into the causal and contextual factors and the unsafe outcomes related to ATCO fatigue. However, there was insufficient detailed information in the data collected and analysed to elicit the relationship between ATCO fatigue-related occurrences and fatigue risk management practices.

3. Caveats regarding the use of ECR data are noted

In the study some deficiencies were observed regarding the data sample on ATCO fatigue-related occurrences in the ECR. The ECR data sample of ATCO fatigue-related occurrences lacked good quality of reporting and completeness. In addition, biases in reporting were evident. In the present study, these issues limited the detailed (statistical) analyses and affected the usability and statistical validity of the safety data analysis results. It cannot be ascertained that the results represent all EASA Member States.

4. The scientific literature on ATCO fatigue in the EU is very limited

Based on the extensive review of the scientific literature, it was shown that the current scientific knowledge on ATCO fatigue in the EU is very limited. Most studies used a relative small number of participants, and the majority of the studies were conducted outside of the EU. The gap analysis that was performed to compare knowledge existing in other domains substantiated the necessity to collect more scientific data on larger representative ATCO and ATSP samples including EU specific practices and procedures (e.g. rosters, type of work, technology, traffic load, positions), to get better insight into the prevalence, causes and impact of ATCO fatigue.

5. Diverse rostering practices were observed in European ATSPs

The interviews with the representative sample of 16 ATSPs revealed varying agreements regarding rostering practices within ATSPs. Rosters are most often constructed using a dedicated software and/or spreadsheets, depending largely on the configuration and operational requirements of each interviewed ATSP and its units. The timing of roster publication varies greatly, not only between ATSPs, but between units as well. All but one ATSP included night duties in their operations. The majority of the ATSPs make regular use of pre-publication requests and post-publication swaps, as long as the resulting roster still complies with the regulations.

6. Integration of fatigue management into the rostering procedure did not pose significant organisational constraints for the ATSPs

Based on the interviews, it was concluded that ATSPs integrate fatigue management into the rostering procedure without any significant organisational constraints for the ATSPs. With respect to ATSPs' soft rules and the integration of fatigue in their operations, all 16 interviewed ATSPs indicated that they have reactive measures in place, whereas the use of proactive measures was clearly much more variable across the ATSPs. Regarding predictive and preventive measures for fatigue risk management, while none of the interviewed ATSPs makes use of biomathematical models, a majority does make use of proactive means to manage the risk of fatigue. Some ATSPs communicate on FRMS related actions and/or offer complementary courses on fatigue risk management. While all ATSPs acknowledged that roster construction played a part in ATCO fatigue, according to the ATSPs the most predominant causes of fatigue in the rosters were the shift length and (the number of) night shifts. The non-roster-related elements most frequently mentioned by ATSPs to contribute to fatigue were workload, the complexity of operations, and traffic load.

7. A large majority of the analysed rosters represent little risk in terms of fatigue

The study analysed 24 actual rosters from a representative sample of 16 ATSPs. The biomathematical models used in the analysis (SAFTE-FAST and FAID) both showed that around 85% of the shifts were associated with a low to moderate risk of fatigue. The roster analysis with the Dawson's fatigue likelihood matrix also showed that a large majority of the analysed roster weeks represented low risk in terms of fatigue, while the rosters offered good opportunities for sufficient sleep.

The expert analysis of the shift schedules used by the ATSPs did not result in any scheduling criteria deviating from scientific recommendations. The shifts and rest times seemed to be well distributed within the analysed rosters, but the rest times before or after night shifts were not always adequate to allow for effective recovery. The number of hours worked turned out to be quite irregular, for which it may be worthwhile to work on a better distribution of working hours per month, and to avoid weeks that are too busy and difficult to recover from. The majority of the analysed rosters complied with the scientific recommendation of a clockwise, fast-paced cycle rotation and contained sufficiently long rest periods in between duties. When comparing the analysis of the biomathematical models (BMMs) and the expert analysis, both considered night shifts to be particularly fatiguing and concluded that the analysed rosters provided good sleep opportunities.

In the subjective data collection campaign, a low exposure to critical levels of fatigue was found. In general, the average fatigue level found in this study proved to be quite low, with a mean SP level of 2.78 (range 1-7) for operational duties. In 5.6% of the studied duties a critical level of fatigue (SP >5) was observed. Most of these critical levels were observed during night or early shifts. In previous studies of aircrew using the same methodology, the percentage of critical fatigue levels was shown to range between 12 and 15% of duties (e.g.

Cabon & Somvang, 2017). In terms of fatigue exposure, the results showed a lower level of fatigue than predicted by the roster analysis. This finding suggests that current ATSP fatigue management practices are relative successful in managing the risk for (high) fatigue.

8. The objective measurements confirm the validity of the subjective fatigue rating scale used

The objective measurements with continuous eye tracking in five ATSPs with 20 volunteer ATCOs during actual ATC operations showed a significant correlation between subjective fatigue and sleepiness on the one hand, and percentual eye closure (PERCLOS) on the other. This finding proved that the subjective fatigue rating scale used during the subjective data collection campaign of this study is a valid measure to detect fatigue in ATCOs.

The findings from the objective measurements also underlined that different types of fatigue related outcome measures (subjective, objective, performance based) can reflect different concepts. They should therefore be seen as complementary to one another, for which ATSPs can consider to apply multiple fatigue measurement methodologies when studying ATCO fatigue (and its effects) in the ops room and/or control tower.

9. Duty type has the highest impact on fatigue

Morning and night duties were shown to significantly increase the risk of critical levels of fatigue when compared to day duties, which can be explained by with the circadian disruption and sleep deprivation these duties generate. Night duties significantly increase the risk of critical fatigue by 253%, compared to an operational day duty. When testing the impact of evening duties as defined by the ATSPs, a significantly lower level of fatigue was observed: evening duties reduced the risk of critical fatigue by –25%. Non-operational duties increased the level of fatigue by +2.27 points but do not appear to have a significant effect on the prevalence of critical fatigue.

<u>Impact of roster-related factors on fatigue</u>

Considering the eight roster elements in the ATCO fatigue regulatory requirements, it appeared that a significant increase of risk was associated with two elements. The factors that increased the risk of critical fatigue were the number of consecutive duty working days and the number of hours per duty period. The number of rest days after a night duty was shown to significantly **reduce** the risk for critical levels of fatigue. These findings are consistent with previous shift-work literature. The key findings are:

- Every additional hour in one work session increases the risk of critical fatigue by 33%.
- Every additional working day increases the risk of critical fatigue by 27%.
- Each additional day of rest following a duty encroaching night-time reduces the risk of critical fatigue in the next duty by 43%.

The ratio of duty periods to breaks, the duration of rest periods, the number of consecutive duties encroaching the night time, or the number of rest periods within a roster cycle were not found to have a significant effect on the risk for critical fatigue as well.

<u>Non-roster-related factors can increase the risk of fatigue</u>

When examining non-roster-related factors, it appeared that monotonous traffic situations, high traffic complexity, and coordination with colleagues or other centres were the factors that most significantly increased fatigue levels. In addition, exposure to monotonous traffic situations and difficult weather conditions not only affected mean fatigue levels but also led to increase in the risk of critical fatigue. The key findings are:

- Difficult weather conditions (low ceilings, limited visibility, high or gusty winds, or thunderstorms) increase the risk of critical level fatigue by 192%.
- Monotonous traffic situations (uneventful or repetitive work conditions) increase the risk of critical fatigue by +120%.
- Sleep debt (percentage of sleep duration compared to the associated individual sleep need) increases the risk of critical fatigue by 80% for each 10% of sleep debt. This highlights the importance of managing the duration and quality of sleep for ATCOs.
- Workload increases mean fatigue levels, but does not lead to a significant increase in the risk for critical fatigue.

Individual and demographic factors do not appear to significantly affect fatigue

Individual factors did not appear to significantly affect chronic fatigue as measured subjectively at baseline. Higher age showed to have a marginal effect on fatigue, although previous research has shown that age decreases tolerance to shift work. This finding might be due to a healthy worker effect masking the age effect, i.e., individuals still working as ATCOs are most tolerant to shift work. Another explanation is that, with age, ATCOs may have more non-operational duties (e.g., administrative, training), reducing their exposure to shift and/or night work. In addition, gender did not seem to be associated with chronic fatigue. The only individual factors that significantly affected fatigue were longer commuting time and a negative perception of the working environment.

10. Non-operational duties should be taken into account

Based on the results of the data collection, differences were found in the fatigue effects of the accumulation of non-operational duties, such as office duties, simulator duties, medical checks, training duties, and other types of non-operational duties. While in the present study no impact of the individual non-operational duties on fatigue levels were identified, fatigue levels were found to increase with every additional non-operational duty hour.

11. Different shift types based on fatigue levels could be identified

Based on the assessment of fatigue risk across different times of the day observed in the data sample collected in the subjective measurement campaign, three distinct duty types were identified. Using this data-driven approach, three separate shifts types could be distinguished in the data sample:

- Morning duties: duties starting between 0200 and 0600 local time.
- Day duties: duties starting after 0600 and ending before 0200 local time.
- Night duties: duties ending between 0200 and 1100 local time.

This categorisation of fatigue levels can be useful in two instances. In order to be able to compare the effects of the (sequence of) different shift types better in the future, clear definitions of the different shift types within these boundaries could be drawn up. ATSPs could also keep in mind this categorisation when building the rosters.

12. Future ATCO supporting technologies may alleviate ATCO workload and fatigue, aided by a tailored, human-centric approach, but may introduce potential hazards too

Future ATCO supporting technologies may bring benefits in relation to ATCO workload and fatigue. Overall, the general, holistic assessment of this study is that a particular set of technologies may reduce workload and, as a result, alleviate fatigue. Since a high workload over time might contribute to fatigue, technologies that have reached maturity level TRL 6 or higher, have the potential to reduce traffic complexity, automate tasks and facilitate looking further ahead in time can help to reduce fatigue.

However, future technologies also bring potential hazards for ATCO workload and fatigue which should be addressed in the development and implementation phase of technology. The report describes several threats related to (future) technology that may have a negative impact on ATCO fatigue. The following fatigue threats were deemed relevant: Loss of sense of control, shift in ATCO task distribution, monotonous situations and low work load/underload situations, and drowsiness. In particular, drowsiness and sleepiness due to combinations of low task load, high monotony in task execution, limited sense of control and working during the night are relevant.

The following points should be considered however:

- The extent to which each of these technologies affects workload and possibly fatigue is wholly dependent on the specific ATCO position in a specific operational environment, considering the specific conditions of the ATSP.
- For various reasons it is not feasible to unanimously quantify the impact of technology on workload and fatigue in general terms, to quantify the added value of the listed technologies in terms of a percentage-change of workload or fatigue, and to draw generalised, broad statements regarding their expected workload and fatigue reduction.

- ATSPs may use a human-centric approach to assess the potential impact of a particular ATCO supporting technology on ATCO workload and fatigue for a specific ATCO position, in the local operational environment, including the circumstances, procedures, interfaces, etc., taking into account the guidance and good practices provided in the report, including those for conducting a Human Performance Assessment (HPA) including a Human-In-The-Loop (HITL) experiment for addressing ATCO fatigue threats of future technology (See recommendation 5, 14, 15, 16).Other factors also influence ATCO fatigue, such as working hours, working conditions, sleep and recovery and the worker's capacity, and these should be considered equally.
- The reduction of workload that could be achieved in the operational practice due to technical advancements may be offset by traffic load increase and workload management strategies of ATSPs.

8.2 Key recommendations

Fatigue is a multi-causal hazard, including work- and non-work related factors, as well as roster- and non-roster related factors. Prevention and mitigation of ATCO fatigue requires therefore a multi-layered and comprehensive approach. For that reason the study has formulated recommendations at different levels, covering ATCO regulatory requirements, guidance, FRMS, practical prevention and mitigation measures, and future research. The key recommendations to EASA are addressed in this section. Section 8.3 provides recommendations for further research.

1. Consider action to achieve a better level-playing field on work and rostering practices

Actions at EU level to achieve a better level-playing field on work and rostering practices could be considered for the future. Although the ATCO fatigue regulatory requirements helped to achieve a more homogenous framework for the prevention and mitigation of ATCO fatigue, it appears from the study that there are qualitative differences in the way that the ATSPs have implemented the ATCO fatigue regulatory requirements, e.g. regarding the policy and information programme. In addition, variance across ATSPs in EU in the eight roster elements and the maximum and minimum values applied by ATSPs are observed as a result of national regulations Furthermore, EASA and national authorities are invited to investigate further, in coordination with the ATSPs, some of the large variations observed during the study.

It is also recommended that national competent authorities reinforce the oversight on the qualitative content of the measures put in place by the ATSPs to implement the ATCO fatigue-related regulatory requirements stemming from Regulations 2015/340 and 2017/373. It is also recommended that the inspectors in charge of the oversight of ATSPs are trained on fatigue risk management and FRMS.

2. Clarify terminology in the ATCO regulatory requirements

The study highlighted that some terms and definitions are not equally understood and applied across ATSPs, which may require more precise definitions or clarification. For example, this was the case for the definition of 'rest/breaks' and 'night-time'. Therefore, it is recommended that EASA clarifies the terminology and definitions where required in the appropriate forums and material. In addition, it may have to ensure coherence with ICAO Doc 9966 provided terminology and guidance

3. Investigate the concerns expressed by the ATCO associations

In the responses provided by the ATCO associations, concerns were expressed on the effectiveness of the fatigue reporting mechanisms and the ATCO fatigue information programme. It is recommended that EASA further investigates the representativeness of these responses and the concerns of the ATCO associations. EASA should make sure that ATSP ensure that the information and awareness on fatigue is effective.

4. Take measures and reinforce means for reporting ATM/ANS and fatigue occurrences according to Regulation (EU) 376/2014

EASA and the competent national and EU authorities are invited to better monitor compliance of ATSPs with the reporting obligations under Regulation 2014/376 with a view to improve the safety occurrence reporting linked to fatigue. In particular, it is recommended that national competent authorities ensure that ATSPs report good quality data on ATCO fatigue-related occurrences in compliance with Regulation 376/2014 and the associated implementing rules. The occurrence reports submitted to the ECR should contain the required level of data/detail to avoid non-uniformity in the level of information is provided. Moreover, the data of the preliminary occurrence reports should be (frequently) updated in the ECR with the latest revision and/or be replaced by the final reports.

EASA should propose common processes for ATSPs to report ATCO fatigue-related occurrences so that uniformity in information can be achieved. These processes should be clear and unambiguous so that ATSPs can easily follow and provide the information accordingly. To that end, the ATSPs in their fatigue management policy and their staff who internally investigate occurrences should ensure that 'fatigue' is systematically considered as being a potential contributory factor in any occurrence submitted by an ATCO. ATSP staff should be properly trained on the occurrence reporting requirements and how to report occurrences, and the reporting system should be clear and easy to use so underreporting can be avoided. As required by the regulation, information about causal and contributing factors should be included in the reports to better understand the causes and effects of fatigue-related occurrences. Details on the ATCO work situation, e.g. shift, work schedule, rostering schedule, previous duty times, etc. should be provided as much as possible in the investigation associated with the reports. The nature of the report should be recorded as 'voluntary' or 'mandatory'. This will enable analysts to compare the share of voluntary and mandatory reports. In addition, ATSPs should process detailed information according to the standard taxonomy of ECCAIRS to ensure data consistency. Information retrieved from reports should be completed in the data fields of the ECR. Using one of three ICAO working languages in Europe (English, French and Spanish) in the occurrence reporting system is highly recommended. It is noted that Regulation (EU) 376/2014 does not restrict the use of native language in reporting occurrences. However, using a limited number of common languages is favourable for enhancing data search and analysis.

A fatigue reporting system can only be effective if ATCOs are informed of and know how to use the fatigue reporting system. The interfaces of the fatigue reporting system should be well-designed for ease of use and ATCOs should be familiar with it. Timely feedback on the follow-up actions and trend analysis arising from inputs to the fatigue reporting system should be provided to give assurance that safety concerns raised have been taken seriously by the organisation. Processes, procedures and policies should be implemented to ensure the integrity of the fatigue reporting and to prevent its misuse, and ensure a safe and just culture. These processes should ensure that the information provided is used to improve safety and not to discipline individuals that filed the report. Good practices defined in section 6.5 should be adopted by ATSPs.

EASA an EU authorities are encouraged to consider improvements to the ECR and ECCAIRs reporting tools and search fields, where needed. Analysis of the ECR database in the context of this study showed anomalies that raise concerns about the quality and completeness of the ECR in terms of ATCO fatigue-related occurrences. Therefore, it is recommended that the EU authorities investigate the reasons why the quality and completeness of the data is not optimal and make the necessary improvements.

A repeat of the analysis of ATCO fatigue-related occurrences should be considered when the data quality and completeness of ATCO fatigue-related occurrence reports in the ECR have reached a level of detail sufficient to conduct a human factors analysis using a comprehensive taxonomy, e.g. after 3 or 5 years. If this study is repeated in the future, strategies should be considered by EASA to enhance the data search in the ECR. For instance, provided that data completeness and level of detail in reports have improved, search terms can be improved, and categorisations for unsafe outcomes can be reconsidered.

5. Consider and adopt guidance and good practices described in the report

EASA is advised to recommend to ATSPs to adopt the guidance and good practices, described in Chapter 6, for the development of rosters, fatigue risk management and FRMS. Particularly, EASA should encourage ATSPs to implement fatigue prevention/mitigation measures that fit the organisation, to monitor the effects of this implementation, and if possible conduct an intervention study into the effectiveness on ATCO fatigue.

In addition, EASA should recommend ATSPs to monitor ATCO fatigue by means of subjective and/or objective measurements during operational practice, in order to obtain more insight into the experienced level of fatigue and the contributing fatigue factors. Fatigue measurements could be applied during specific data collection periods, specific shifts, or on a continuous basis. Since it was found that different types of fatigue-related outcome measures (subjective, objective, performance based) are complementary, utilising multiple types of fatigue measures offers the most comprehensive understanding of the fatigue levels and performance capabilities of ATCOs. To be able to this, ATSPs, researchers and regulators should seek for practicable and valid (technological) solutions for fatigue monitoring and/or detection to be implemented alongside subjective fatigue ratings, as part of possible reactive FRM measures. The report provides examples of promising new technologies to perform real-time monitoring, but it must be acknowledged that more (validation) studies of these technologies need to be undertaken in the ATC environment. Ethical and data privacy issues also have to be resolved.

6. Monitor and collect data on the effectiveness of ATCO fatigue prevention/mitigation measures

Most measures deemed most effective and applicable to reduce and/or mitigate ATCO fatigue, mentioned in this report (section 6.4.3), require additional well-designed intervention research to monitor the effects of these measures once they have been implemented. Furthermore, additional data collection is recommended because the evidence for the effectivity of these measures in ATSPs and ATCOs is still scarce and the potential benefit of specific operational and organizational conditions may be context dependent. Such data collection will help increase the collective knowledge in the EU.

To this end, ATSPs are notably encouraged to share knowledge on a regular basis on (the prevalence, causes and effects of) ATCO fatigue, fatigue data collection, and on best practices regarding fatigue mitigation and prevention. Establishing a regular forum for knowledge sharing could help to increase the common understanding about ATCO fatigue, and effective prevention and mitigation measures, and streamline the research undertaken, for example contributing to a more uniform way of data collection. In addition, if ATSPs conduct fatigue-related research and publish the results in peer-reviewed journals (e.g. through a collaboration with scientific institutes), the quality of the existing scientific knowledge about ATCO fatigue in Europe will increase further and the outcomes will be better comparable with the prevalence of ATCO fatigue in other continents and/or other domains.

7. Monitor the ATCO-hour productivity to assess the impact of ATCO fatigue regulatory requirements

The fluctuations in aircraft flight hours due to the COVID-19 pandemic make it impossible to assess the effects of the ATCO fatigue regulatory requirements on ATCO-hour productivity. Therefore, it is recommended that EASA continues monitoring ATCO-hour productivity and assess the possible impact of ATCO fatigue on ATCO-hour productivity when the traffic volumes have fully returned to pre-COVID levels.

8. Take action to ensure and facilitate appropriate consideration of ATCO fatigue and fatigue threats in the development and implementation of (future) ATCO supporting technologies.

EASA is recommended to develop policy measures in the form of for example guidance material to ensure appropriate consideration of ATCO fatigue and fatigue threats in the development and deployment of (future) ATCO supporting technology. More specifically, EASA may consider initiatives to enable the development and implementation of technological innovations with sufficient and appropriate attention to ATCO fatigue and fatigue threats:

- Develop guidelines for stakeholders to adopt a human-centric approach and good practices for conducting Human Performance Assessments /Human-in-the-loop experiments that also address ATCO fatigue. The step-by-step approach and the guidance described in Annex G may be used as a starting point.
- Specify in such guidance that stakeholders should take into account ATCO fatigue and operational conditions that are conducive of fatigue (e.g. working at night-time, prolonged periods of high and low workload, high monotony in task execution) in the design, development and evaluation of (future) technologies.
- An assessment of fatigue risks of the involved technology should take place in the research and development phase of new technologies, and also before the implementation of such technologies by ATSPs. This could include:

- To identify, assess and mitigate fatigue threats related to the involved technology, including the threats mentioned in section 7.2.
- To apply scenarios that are representative of actual working conditions, including working at night, and scenarios involving high and low workload.
- To assess and mitigate the risk of ATCO drowsiness and sleepiness as a results of combinations of low task load, high monotony in task execution, limited sense of control and working during the night.
- To evaluate if ATCO fatigue has an impact on cognitive tasks and task performance when working with (future) ATCO supporting technology during the design and development phase of (future) technology.
- If human-in-the-loop experiments are conducted, they should be performed not only with well-rested ATCOs during day-time but also with fatigued ATCOs (e.g. representing night-time operations).
- Allow stakeholders to identify and use additional means for assessment that are appropriate and proportional to the complexity and maturity level of the technology involved and the specific operational conditions.

9. Encourage ATSPs to maximise the potential benefit of (future) ATCO supporting technology in reducing ATCO workload and fatigue

Future ATCO supporting technology may bring benefits in relation to ATCO workload and fatigue. A list of (future) technologies and concepts that ATSPs could consider when aiming to reduce workload and fatigue can be found in Chapter 7. When seeking to leverage the potential benefits of (future) ATCO supporting technology in reducing ATCO workload and fatigue, ATSPs are recommended to first identify for each specific ATCO position which limited set of cognitive or operational tasks determine high workload under which circumstances. Next, ATSPs could consider technologies and concepts that a) reduce those specific task loads, b) assist the ATCO to look ahead further in time, and/or c) distribute tasks more evenly over time and between ATCOs.

The extent to which technology reduces workload and possibly fatigue is wholly dependent on the specific ATCO position in a specific operational environment, including for example the circumstances, procedures, interfaces, weather conditions. Therefore, the following is recommended for these specific settings:

- EASA is advised to ensure that ATSPs, ATM/ANS ground equipment manufacturers and the R&D community adopt the human-centric approach and good practices (as outlined in Annex G) to assess and mitigate fatigue threats as a result of (future) technology for a specific ATCO position and the local operational conditions. In particular, it is recommended to take into consideration drowsiness, sleepiness and lapses of attention due to combinations of low task load, high monotony in task execution, limited sense of control and working during the night. Consideration of these threats will constitute an important complement to assessments of hazards related to high workload, which are more common practice.
- ATSPs, ATM/ANS ground equipment manufactures and the R&D community should not only assess workload but also ATCO fatigue as part of a Human Performance Assessment (HPA) or Human-In-the-Loop (HITL) experiments using scenarios that are representative of actual working condition, e.g. working at night and conducting simulations with fatigued ATCOs. It is recommended to consider ATCO fatigue and operational conditions that are conducive of fatigue (e.g. night-time, prolonged periods of high workload, monotonous situations) in such assessments and experiments.
- EASA should advise ATSPs to assess the impact of ATCO supporting technology on ATCO fatigue in an integral fashion and not in isolation, since fatigue is a multi-faceted hazard. An integral approach includes fatigue prevention and mitigation measures, and fatigue and workload management practises covered in the previous sections. When ATSPs wish to manage the risk of high workload in relation to ATCO fatigue, the time on task, the traffic volumes and complexity, the rostering system, sleep and recovery intervention strategies are relevant factors to consider. It is also important to measure the effect of the technologies applied/implemented, by means of measuring both workload and fatigue through validated measures.
- The impact of ATCO fatigue on cognitive tasks and task performance when working with (future) ATCO supporting technology should be addressed in the design and development phase of (future)

technology. When designing and developing ATCO supporting technologies, stakeholders should consider the influence of fatigue on cognitive processes and how those cognitive processes are being supported or influenced by technology. This assessment should be conducted by human factors experts, considering the potential effects of the technology on various cognitive processes most affected by fatigue, as described in the scientific literature. This assessment could be carried out through cognitive task analysis to identify the cognitive processes most involved in using this technology. In this way, (future) technology can be designed to support ATCOs when cognitive task performance is impaired due to fatigue or drowsiness. It is noted that this is in addition to the recommendation to conduct human-in-the-loop experiments in conditions that pose a high fatigue risk (e.g. at night) and with tired ATCOs.

EASA should recommend that stakeholders continue to involve operational staff in the development of (future) ATCO supporting technology. Operational staff should be directly involved in the design, development and evaluation phase of (future) ATCO supporting technologies to collect their feedback on relevant ATCO fatigue-related issues. The following aspects are examples of issues to address in the consultation with ATCOs: Interchanging functions between systems and several humans, predictability of automated task execution, clarity about authority sharing between humans and machines, decision-making when the relevant information might be too complex for a human to comprehend quickly, passively receiving information, trust in integrated information and system-derived advices, variable task load and individual management of workload.

10. Promote and facilitate further research on ATCO fatigue and dissemination of results

EASA is further advised to promote the current study's results and to support knowledge sharing about the prevalence, causes and impact of ATCO fatigue. Research actors are encouraged to publish fatigue-related research in peer-reviewed journals (e.g. through a collaboration with scientific institutes), so that the quality of the existing scientific knowledge about EU ATCO fatigue will increase further and the outcomes will be able to be compared with ATCO fatigue data from other continents and/or other domains.

Although this study tackled quite some knowledge gaps, EASA is recommended to promote further research in ATCO fatigue. The study has identified several topics for which additional, experimental research, using simulations for instance would be useful.

8.3 Recommendations for further research

This section proposes recommendations and considerations for future research with the aim to further increase the knowledge and scientific evidence on ATCO fatigue prevalence, causes and effects, and effective prevention and mitigation, and thereby support future decision-making by EASA.

11. Recommendations for future research

Taking into account the aspects listed in this report, further relevant and scientific knowledge about the prevalence, causes and impact of ATCO fatigue in Europe could be acquired to deepen and substantiate the results. The following topics for further research were identified:

- Research into the correlation of the average values of the eight roster elements with traffic volumes and complexity, seasonal activities, and nominal and non-nominal situations. This could be reached through collecting data during longer (e.g. several months) and more varied measurement periods (e.g. both summer and winter) as compared to the current study, targeting ATSPs with specific schedules, work procedures, and variation in traffic volumes and complexity.
- A longer data collection period could also shed more light on the effect of the number of working hours per week on (cumulative) ATCO fatigue, and thereby add to possible regulation regarding the maximum number of working hours given a certain period.
- Research into the adequate values for the amount of overtime hours in case of exceptional operational situations, as well as the accompanying measures that need to be taken into account to assure appropriate levels of safety.
- Research into a more common definition both 'working hours' and the different types of shifts used in EU ATSPs in order to be able to better compare fatigue levels between ATSPs, as well as to determine the influence of the schedules applied.

Based on the limitations of the current observational study, further research should also try to address the following:

- To include a more varied sample of participants and thereby also ATCOs of the oldest age group;
- To take into account the nature of non-operational duties and measure the effect of these duties on fatigue and performance.
- To assess the impact of new technologies on fatigue in an objective manner, while controlling for other factors (such as rostering and workload).

Given the limitations that were encountered during the present study, future research addressing these topics may have a more experimental nature, requiring human-in-the-loop experiments e.g. using simulator(s) or a highly controlled operational environment.

12. Consider real-time eye tracking for scientific studies on ATCO fatigue

Although in this study the practical implementation and execution of real-time eye tracking proved to be time consuming and laborious for continuous usage in ATSPs, it is worthwhile to consider this technique for scientific research. In addition, while the adoption of the existing available technologies by ATSPs can be difficult, the current developments in fatigue detection technologies should be closely followed, and new devices and/or applications that become available should be studied (see next recommendation).

13. Conduct further research into the feasibility and validation of (new) objective measurement techniques in the ATC operational environment

It is recommended to further evaluate the feasibility and validation of (new) objective fatigue monitoring technologies (for instance wireless EEG, speech analysis and web-cam based eye tracking) in the control room since they could make it possible to monitor fatigue continuously and in a non-intrusive manner. However, the implementation of these monitoring technologies raises concerns related to ethics and data privacy, particularly in the context of General Data Protection Regulation (GDPR) guidelines. Striking a balance between leveraging the benefits of advanced monitoring technologies and safeguarding individual privacy is crucial. Future developments in fatigue detection and/or monitoring should therefore navigate this challenge by integrating robust data protection measures, ensuring compliance with regulations, and addressing ethical considerations to gain acceptance within the ATC community. As these technologies continue to evolve, ongoing collaboration between researchers, technology developers, and regulatory bodies is strongly recommended.

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Annex A Stakeholder engagement and communication

A.1 Background and scope

The study encompassed a non-technical workstream focused on *'Communication, Dissemination, Knowledge-Sharing, and Stakeholder Management*.' This work aimed to pinpoint optimal communication formats and methods for transferring acquired knowledge in alignment with the identified dissemination goals. These goals spanned from initially creating awareness about the study to ultimately establishing a lasting impact on its target groups.

A.2 Approach

In February 2023, EASA approved the study's communication and stakeholder management plan under study deliverables D-4.A and D-4.B. In relation to stakeholders, this document formally identified 14 stakeholder groups that needed to be considered, managed and engaged throughout the study. Using established stakeholder management methodology, this plan prioritised stakeholders assessed each group's levels of involvement, interest, and influence on the study, allowing EASA to prioritise stakeholder management and actions by stakeholder group. The plan concluded with an activity schedule for the lifetime of the study, and a range of channels to effectively inform and engage each stakeholder group.

A.3 Consultation Meetings

A significant portion of the study's stakeholder engagement endeavours revolved around consultation meetings and presentations to EASA advisory bodies and working groups. These forums provided a platform for the study team to connect with key personnel within EASA and senior industry figures nominated to participate in advisory groups. These sessions served as valuable opportunities to share progress updates and gather insightful opinions, feedback and suggestions. A summary of the study's consultation meetings is presented in the Table A-1 below.

Table A-1: List of ATSPs participating in the study in interviews, and/or roster analysis and/or measurement campaigns.

Date	Audience	Purpose
April 2023	EASA ATCO Steering Group	Progress update and methodology briefing
April 2023	ATM/ANS TeC	Progress update and methodology briefing
June 2023	EASA Human Factors CAG	Progress update and methodology briefing
November 2023	EASA Executive Director	Briefing on the main study results ahead of further stakeholder engagements
November 2023	Joint ATM/ANS Tec and TeB	Present interim results and methodology
December 2023	EASA ATCO Steering Group	Present interim results and methodology
December 2023	EASA MAB	Present interim results and methodology
December 2023	Public	Present interim results and methodology

A.4 Stakeholder Workshops and Webinars

In addition to consultation meetings, the study also effectively hosted two stakeholder engagement webinars and an online dissemination event.

A.4.1 Knowledge-Sharing Workshop – June 2023

Initially, the stakeholder management plan hinted at a stakeholder webinar in June 2023, aiming to connect with and inform secondary stakeholders—those not directly involved in the primary research of the study—about the study's progress. The goal was to share preliminary results and encourage inclusive participation from all study stakeholders and the broader European ATC community.

However, following additional considerations and discussions between EASA and the consortium, the purpose and approach of this webinar underwent slight modifications. At EASA's request, in June 2023, the consortium delivered a stakeholder knowledge-sharing online workshop. The objective was to invite study stakeholders with prior experience in performing or commissioning high-quality research/studies on ATCO fatigue. Shortlisted participants were invited to present their research and findings during the meeting, with a preference for those referenced in the study's literature review or known to EASA for commissioning research in this field. The session also served as a platform for expert group discussions.

The workshop was successfully conducted, featuring six guest speakers from Skyguide, Eurocontrol, LFV, Austro Control, ENAV, and Airnav Ireland. Additionally, 15 participants from the industry attended, including researchers and staff from the consortium and EASA.

A post-event survey was circulated to gauge stakeholder satisfaction with the workshop.

- All respondents rated the meeting as either 'Excellent' or 'Good.'
- Over 90% of respondents indicated that the meeting met their expectations.
- Over 90% of respondents found the content interesting and relevant to their work.
- Over 90% of respondents rated the pre-meeting organization/communication as 'Excellent' or 'Good.'

A.4.2 Public Consultation Webinar – December 2023

In December 2023, the consortium and EASA collaboratively hosted an online public consultation webinar. The primary objective of this event was to engage and inform a diverse array of stakeholders about the study's ongoing developments and, when possible, share some initial results. This webinar played a crucial role in the study’s commitment to fostering an open and inclusive research study, ensuring that all key stakeholders had a platform to be heard and informed. Moreover, the workshop provided a valuable opportunity for key stakeholders to offer feedback on the interim results.

A total of 185 verified individuals attended the event, with 97 actively participating in Slido polls and the Q&A session. In the post-satisfaction survey, 93% of respondents rated the webinar as either 'Excellent' or 'Good.' When questioned about whether the workshop met participants' expectations, 80% answered affirmatively, with an additional 17% expressing a 'somewhat' response.

A.4.3 Dissemination Event – February 2024

A concluding webinar took place in February 2024, serving as a public online dissemination event. The consortium and EASA presented key study outcomes, results, and recommendations during a comprehensive public-level online dissemination.

A.5 Communication and dissemination

In accordance with the tender specifications, a comprehensive set of communication materials were created to facilitate the dissemination of study findings, recommendations, and results. A concise video study was produced as part of this suite, serving as an introductory piece to set the stage and generate interest and anticipation. At the time of writing, this video is scheduled for publication across other EASA media channels. Additionally, an informative infographic was crafted to clearly emphasise key facts and figures extracted from the study. Finally, a series of GIF files were developed to underscore essential messages derived from the study results. These GIFs aimed not only to highlight crucial insights but also to promote the final report. The collective goal of these communication materials is to effectively convey the study's outcomes and engage the audience in a meaningful way.

A.6 Stakeholder participation

ATSPs

Six ATSPs participated in the subjective data collection campaign (AirNav Ireland, ANS CZ, DSNA, ISAVIA, MUAC and Skyguide). Five of the six ATSPs also participated in the objective measurement campaign in the OPS room or air traffic control tower. Other ATSPs contributed to this study in various research activities, including the interviews and/or roster analysis. These ATSPs are listed in the Table A-2 and shown in orange in Figure A-1.

Table A-2: List of ATSPs participating in the study in interviews, and/or roster analysis and/or measurement campaigns.

ATSPs participating in the study		
Aircraft Industries	ENAV	PANSA
AirNav Ireland	HungaroControl	Romatsa
ANS CZ	ISAVIA	Saerco
Austro Control	LET	SDATS
DFS	LFV	Skyguide
DSNA	LGS	Slovenia Control
EANS	LVNL	
ENAIRE	MUAC	

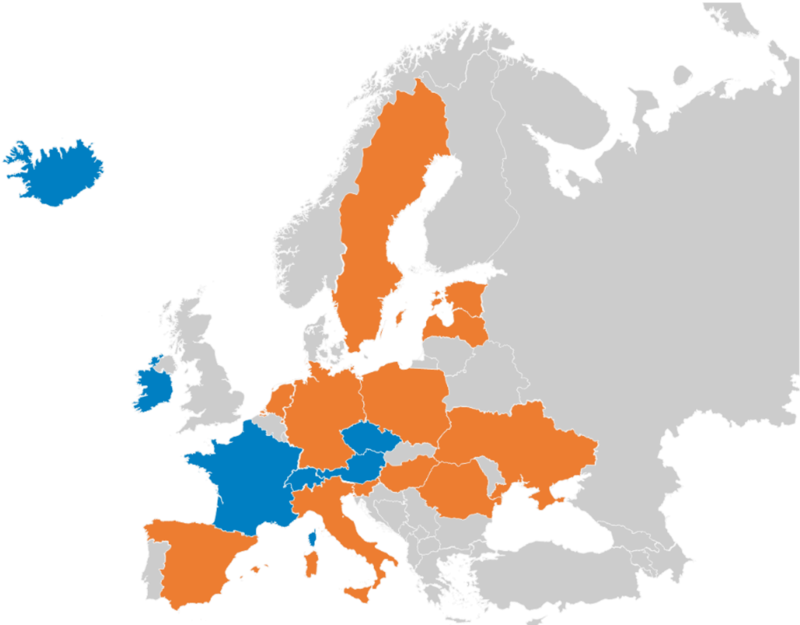

Figure A-1: Geographical distribution of participating ATSPs (blue colour represents ATSPs that participated in the measurement campaigns).

The overview of ATSP, responding to the survey om the implementation of ATCO fatigue-related regulations, is shown in Table A-3.

Table A-3: List of ATSPs responding to the survey (and country).

Director Department of Civil Aviation Ministry of Communications and Works – Cyprus (CY)	Hellenic Aviation Service Provider (EL)	Aircraft Industries (CZ)	Donegal Airport (IE)
Maastricht Upper Area Centre (NL/BE/DE/LU)	Avinor Flysikring (NO)	Skyguide (CH)	Sligo North West Airport Company (IE)
PANSA (PL)	Isavia (IS)	Bulgarian Air Traffic Services Authority (BULATSA) (BG)	ENAV (IT)
ROMATSA (RO)	ENAIRE (ES)	Luftfartsverket (LFV) (SE)	Direction des Services de la Navigation Aérienne (DSNA) (FR)
Croatia Control (HR)	SAERCO (ES	SAAB Digital Air Traffic Solutions (SDATS) (SE)	Estonian Air Navigation Service Provider (EE)
Navegação Aérea de Portugal (NAV Portugal) (PT)	Skyway (ES)	Arvidsjaur Flygplats (SE)	Rhein-Neckar Flugplatz (DE)
SJSC “Latvijas gaisa satiksme" (LGS) (LV)	Fintraffic Air Navigation Services (FI)	Operations and Strategy Directorate Irish Aviation Authority / AIRNAV (IE)	Deutsche Flugsicherung (DFS) (DE)
HungaroControl, Hungarian Air Navigation Services Private (HU)	Řízení letového provozu České republiky (ANS CZ) (CZ)	Waterford Regional Airport (IE)	Skeyes (BE)
SLOVENIA CONTROL (SL)	AERO Vodochody Aerospace (CZ)	Kerry Airport (IE)	Administration de la Navigation Aérienne (ANA) (LU)

ATCO associations

The study team distributed through EASA a survey to International Federation of Air Traffic Controllers' Associations (IFATCA), Air Traffic Controllers European Unions Coordination (ATCEUC) and European Transport Workers Federation (ETF) to collect the views of their members on the implementation of the ATCO fatigue regulatory requirements through open questions. ETF provided written responses. IFATCA forwarded the questionnaire to its members asking them to reply directly to the study team. The ATCEUC provided the anonymised responses from 16 of their member unions. For a few questions an overall response was formulated by ATCEUC. The response from the Belgian Guild of Air Traffic Controllers was provided directly to the research team. In this report, the respondents to this survey are referred to as “ATCO associations”.

National Supervisory Authorities/National Aviation Authorities

The study team distributed through EASA a survey to the National Supervisory Authorities (NSAs)/National Aviation Authorities (NAAs) to collect information on the implementation and the effect of EU regulations on ATCO fatigue, notably Commission Implementing Regulation (EU) 2017/373 and 2015/340. The survey was send to all NSAs/NAAs in the EASA Member States and in total 10 responses were collected. There are in total 30 NSAs in the 31 EASA Member States. Only Liechtenstein does not have a NSA.

Annex B ATCO fatigue regulatory requirements

B.1 Introduction

The 2008 Basic Regulation[28] requires that the provision of ATM/ANS and the air traffic controllers involved in the provision of ATM/ANS comply with the essential requirements set out in the annexes of the Basic Regulation. One of these essential requirements states that the provision of ATC services shall not be undertaken unless the prevention of fatigue of personnel providing an ATC service is managed through a rostering system, to be structured by an adequate balance of duty and rest periods. Such rostering systems are to be established by taking into account factors contributing to generate fatigue, such as sleep deprivation, disruption of circadian cycles, night hours, cumulative duty time for given periods of time and also the sharing of allocated tasks between personnel.

As a consequence of these requirements in the Basic Regulation, EASA developed legislative measures to implement this requirement. In October 2010, the RMT.0148 – Working Group 06 'Human Factors' was initiated consisting of human factor experts from EASA, ATSPs, NAAs, Unions, IFATCA and EUROCONTROL. The result of this working group was a proposal to amend the regulations (NPA 2013-08) in May 2013 and Opinion No 03/2014 issued in December 2014. Successive thematic meetings were held to fine-tune the AMC and GM. As a result, requirements on ATCO fatigue were included in Commission Implementing Regulation 2017/373 which was published in March 2017. Associated AMC and GM were published within EASA ED Decision 2017/001/R.

Beside the requirements stated in the Basic Regulation and Regulation (EU) 2017/373, ATCO fatigue-related requirements for ATSPs are also specified in Commission Regulation (EU) 2015/340. This regulation requires that, as part of the ATCO's licensing scheme, training on human factors shall include a programme on the prevention of fatigue. Regulation (EU) 2015/340 was adopted on 20 February 2015 and applied from 30 June 2015.

The requirements related to ATCO fatigue in Regulation (EU) 2017/373 and Regulation (EU) 2015/340 are in this report referred to as the "ATCO fatigue regulatory requirements" and they are presented below.

B.2 Regulation (EU) 2017/373

Commission Implementing Regulation (EU) 2017/373, adopted in March 2017 and applied as of January 2020, imposes a number of specific requirements on air traffic service providers linked to ATCO fatigue.

In Annex IV (Part-ATS), Subpart A (Additional Organisation Requirements for Providers of Air Traffic Services (ATS.OR)), section 3, specific human factors requirements for air traffic control service providers are provided. In this section requirements ATS.OR.300 (Scope), ATS.OR.315 (Fatigue) and ATS.OR.320 (Air traffic controllers' rostering system(s)) provide specific requirements linked to ATCO fatigue.

ATS.OR.300 Scope

This section establishes the requirements to be met by the air traffic control service provider with regard to human performance in order to:

(a) prevent and mitigate the risk that air traffic control service is provided by air traffic controllers with problematic use of psychoactive substances;
(b) prevent and mitigate the negative effects of stress on air traffic controllers to ensure the safety of air traffic;

[28] Regulation 216/2008 which was later replaced by Regulation (EU) 2018/1139

(c) prevent and mitigate the negative effects of fatigue on air traffic controllers to ensure the safety of air traffic.

ATS.OR.315 Fatigue

In accordance with point ATS.OR.200 (Safety Management System), an air traffic control service provider shall:

(a) develop and maintain a policy for the management of air traffic controllers' fatigue;

(b) provide air traffic controllers with information programmes on the prevention of fatigue, complementing human factors training provided in accordance with Sections 3 and 4 of Subpart D of Annex I to Regulation (EU) 2015/340.

ATS.OR.320 Air traffic controllers' rostering system(s)

(a) An air traffic control service provider shall develop, implement and monitor a rostering system in order to manage the risks of occupational fatigue of air traffic controllers through a safe alternation of duty and rest periods. Within the rostering system, the air traffic control service provider shall specify the following elements:
  (1) maximum consecutive working days with duty;
  (2) maximum hours per duty period;
  (3) maximum time providing air traffic control service without breaks;
  (4) the ratio of duty periods to breaks when providing air traffic control service;
  (5) minimum rest periods;
  (6) maximum consecutive duty periods encroaching the night time, if applicable, depending upon the operating hours of the air traffic control unit concerned;
  (7) minimum rest period after a duty period encroaching the night time;
  (8) minimum number of rest periods within a roster cycle.

(b) An air traffic control services provider shall consult those air traffic controllers who will be subject to the rostering system, or, as applicable, their representatives, during its development and its application, to identify and mitigate risks concerning fatigue which could be due to the rostering system itself.

In addition to these three articles, two Acceptable Means of Compliances (AMCs) are provided:

AMC1 ATS.OR.315(a) Fatigue Management Policy

(a) The air traffic controllers' fatigue management policy should:
  (1) declare the commitment to proactively and systematically monitor and manage fatigue and describe the expected benefits for the safety of operations;
  (2) be signed by the accountable manager;
  (3) address the mitigation of the operational impact of air traffic controllers' fatigue;
  (4) be communicated, with visible endorsement, throughout the air traffic control service provider;
  (5) include a commitment to:
    (i) consider the best practices;
    (ii) provide appropriate resources; and
    (iii) enforce fatigue management as a responsibility of managers, staff involved in fatigue management procedures and air traffic controllers;
  (6) be periodically reviewed to ensure it remains relevant and appropriate.

(b) In accordance with the policy in point (a), the air traffic control service provider should establish and implement:
  (1) principles and procedures to enable fatigue reporting;
  (2) principles and procedures for occurrence investigation and analysis to consider fatigue as contributing factor;

(3) procedures for the identification and management of the effect of fatigue on the safety of operations.

AMC1 ATS.OR.320(a)(6);(7) Air traffic controllers' rostering system(s)
NIGHT TIME: Night time should be considered as the time between midnight and 05.59.

Guidance Material (GM) is provided to the articles ATS.OR.300 (Scope), ATS.OR.315 (Fatigue) and ATS.OR.320 (Air traffic controllers' rostering system(s)) of Regulation (EU) 2017/373 and the Acceptable Means of Compliances (AMCs). In the Guidance Material, reference is made to ICAO Doc 9966 "Manual for the Oversight of Fatigue Management Approaches" (ICAO, 2016), "EUROCONTROL Study on Shiftwork practices – ATM and related Industries" (EUROCONTROL, 2006) and "Fatigue and Sleep Management: Personal strategies for decreasing the effects of fatigue in air traffic control" (EUROCONTROL, 2005)[29]. Apart from the three documents referred to as Guidance Material, additional supporting material is available including 'Fatigue Management Guide for Air Traffic Service Providers' published by CANSO, ICAO and IFATCA (2016) and CAP 670 Air Traffic Services Safety Requirements published by the CAA UK (2019).

B.3 Regulation (EU) 2015/340

Commission Regulation (EU) 2015/340, laying down technical requirements and administrative procedures relating to air traffic controllers' licences and certificates, was adopted on 20 February 2015 and applicable from 30 June 2015. Article 11 of the Regulation gave the possibility to Member States to notify to the Commission and EASA a derogation in order not to apply Annexes I to IV in whole or in part before 31 December 2016. All Member States, except two, made use of this possibility and applied the Annexes only after 31 December 2016.

Regulation (EU) 2015/340 imposes, as part of the ATCO's licensing scheme, that the prevention of fatigue is included as a subtopic in the training programme on human factors.

[29] In 2018, EUROCONTROL published a renewed version of this document (EUROCONTROL, 2018).

Annex C Research approach

C.1 Data collection on the implementation of ATCO fatigue regulatory requirements

For the evaluation of the implementation of ATCO fatigue regulatory requirements and the assessment of their effectiveness and efficiency, data was collected through various means:

- A survey was distributed amongst the ATSPs in the EASA Member States. The goal of the survey was to collect quantitative data on the implementation, effectiveness and efficiency of ATCO fatigue provisions.
- Interviews with a representative sample of 18 ATSPs. The goal of the interviews was to gather more comprehensive and qualitative information than what can be collected through the survey.
- Written responses to open questions by ATCO associations. IFATCA, ATCEUC and ETF were invited to collect the views of their members on the implementation of the ATCO fatigue regulatory requirements through open questions.
- Written responses to open questions by NSAs of the EASA Member States.
- The main sources of information for the desk research were:
  - Applicable regulations on ATCO fatigue.
  - Guidance material developed by EUROCONTROL, ICAO, CANSO, IFATCA and the UK CAA.
  - ATCO fatigue policies and related documentation received from six ATSPs during the interviews.
  - Results from EASA standardisation inspections. In the period 2020 – 2022 standardisation inspections were performed by EASA that covered the ATCO fatigue regulatory requirements ATS.OR.300, ATS.OR.315 and ATS.OR.320 in all EASA Member States.
  - Data from Eurocontrol on traffic volumes (number of flights and composite flight-hours) and ATCO hour productivity for the period 2002 – 2021.
  - Results from a survey conducted in 2018 by CANSO on rosters (15 ATSPs responded to this survey).

The substantiation for the representativeness of the sample of ATSPs can be found in the study deliverable D-1.A.1. For further information on the approach and results of the assessment of the implementation of ATCO fatigue-related regulations refer to the study deliverables D-1.A.2 & D-1.B.

C.2 Literature review

C.2.1 Peer-reviewed scientific literature search

The research team compiled an overview of the existing literature by conducting a literature search on the 16th of February 2023, using the electronic databases Scopus, Pubmed and Psychnet. To combine exposure variables (i.e. work schedules) with search terms relating to the occupational nature (i.e., air traffic control) and the relevant fatigue-related outcome measures (i.e. fatigue, alertness), the following search terms were used for the search strategy: 1. Air traffic service provider, ATSP, Air Navigation service provider, ANSP, Air traffic control, ATCO, air traffic control service(s), flight control, ATM, air traffic management, air traffic service unit, ATSU AND 2. fatigue, boredom, drowsiness, sleep, attention, sleepiness, alertness, vigilance, workload.

The inclusion criteria used included the following:

- language: English, French, German and Dutch;
- publication date: 2000 and later only;
- both military and civil air traffic control studies were included.

To find additional relevant studies based on the initial outcomes, in the last week of February 2023, the research team also screened:

- Bibliographies of systematic and non-systematic review articles;
- Reference lists of all articles eligible for full-text screening (snowball sampling).

C.2.2 Grey literature search

In addition to the systematic literature search on peer-reviewed articles, experts from within the network of the consortium and EASA were asked to provide additional 'grey' literature. Grey literature is research material by organisations outside the traditional commercial or academic publishing and distribution channels. It can include, amongst others, theses, dissertations, research and committee reports, government reports, conference papers, and ongoing research.

C.2.3 Analysis of literature

The articles were systematically assessed with emphasis on the following topics in order to be included:

- Describe data on ATCO fatigue or related aspects (alertness, vigilance, sustained attention) or a fatigue-related outcome;
- Involve real ATCOs (either in the lab or in the field);
- Reflect real ATCO work (and not a test/task that resembled this);
- Quality (determined by means of the NIH Study Quality Assessment Tools).

The collected information was subsequently summarised using the extracted study data and synthesising the studies' findings. To determine the current level of knowledge regarding the causes of ATCO occupational fatigue, its impact on alertness and performance, and the relationship with safety risks, data from studies that were rated as being 'good' or 'fair' were extracted only. Further details and analysis results can be found in the study deliverable D-2.A.

C.2.4 Gap analysis with literature from other domains

The objective of the gap analysis was to identify the issues that appear to be missing or not sufficiently covered in the existing literature on ATCO fatigue in comparison with the other domains. The gap analysis was performed as follows. An additional literature search was performed in the following domains:

- Aircrew members (restricted to crew members exposed to short-haul flights, and therefore experience a minimal number of time zone crossings during their duties);
- Operators working in shift schedules (day, evening and night shifts; on-call duties) from various domains (e.g. healthcare workers, train drivers and railway traffic controllers, operators at nuclear power plants and oil rigs) who have safety critical tasks, and/or operate in a control room like setting.

This additional literature research in the other relevant domains focused on (systematic or narrative) review articles only, combining the results of different unique studies. References cited within the retrieved papers were reviewed to identify other useful research studies.

Next, information about the prevalence, causes and impact of fatigue, and possible mitigating factors, was extracted from the literature found. In addition, for each of the findings, it was considered if they could be applicable for ATCOs as well. If possible and presented, employee's fitness levels in the other domains was taken into account to prevent misinterpretation of the comparison with the regularly medically checked ATCOs. The research team compared the outcomes of the ATCO-specific literature search to the existing knowledge on fatigue in the other relevant domains and listed the main gaps in consultation with EASA subject matter experts. Further details and analysis results can be found in the study deliverables D-2.A.1, D-2.A.2, and D-2.A.3.

C.3 Analysis of ATCO fatigue-related occurrences

C.3.1 Approach

The approach adopted in collecting and analysing the ATCO fatigue-related data was comprised of five steps as described in the following:

Step 1: Select usable and reliable data sources
In this step, usable data sources in the form of electronic databases for the scope of the study were selected.

Step 2: Develop selection criteria
In this step, data selection criteria were developed to specify which types of data in those sources are relevant to this study. These criteria establish a demarcation for selecting relevant ATCO fatigue-related data. The criteria applicable for the data search include the time period (previous ten years), the geographical region of the EASA Member States, including the UK (until 2020), and the collection of keywords or a taxonomy relevant to fatigue of ATCOs on duty. To establish a set of keywords for use in the data search, EASA was consulted for acceptance of use. A data query with combinations of keywords was developed for data selection.

Step 3: Apply the selection criteria and select the relevant data
In this step, the selection criteria and data query, as established in step 2, were applied to the data sources selected in step 1 in order to filter out the data potentially relevant to the study. A data set was then compiled. The data records obtained were reviewed by a team of safety experts to determine whether the records were relevant to the study. After the initial review, the safety experts organised a consensus meeting to discuss the relevance and inclusion of records in the final data set for analysis. They retained those occurrences in which it was clearly stated in the narrative or headline that ATCO fatigue was a causal or contributing factor. The compiled data underwent a further process of detailed review, selection for relevance, and provision with appropriate categories for cause(s) of fatigue and for unsafe outcome(s). The relevant causal and circumstantial factors were assigned or categorised for each selected case.

Step 4: Analyse the data
After a set of relevant data was generated through the review process, selection of relevance and provision of categorisation as described in step 3, a statistical analysis of different variables (agreed upon with EASA) was performed.

Step 5: Discuss the data analysis results
This last step provided observations and a discussion of the results obtained from the data analyses.

C.3.2 Selection of data sources

The data on ATCO fatigue-related occurrences were queried from two data sources: the European Central Repository (ECR) and the NLR Air Safety Database.

European Central Repository

Following Regulation (EU) 376/2014 on the reporting, analysis and follow-up of occurrences in civil aviation, each organisation established in an EU Member State must set up mandatory and voluntary reporting systems for collecting, evaluating, processing, analysing and storing occurrences reported. Each EU Member State must submit the occurrences they have collected to a European Central Repository (ECR) that the European Commission manages. The ECR is thus the central database of all occurrences (accidents, serious incidents and incidents) and other safety-related information reported to the competent authorities of the EASA Member States. As specified in EU Regulation 376/2014, all safety-related information derived from occurrence reports collected in the Union should be transferred to the European Central Repository in a timely manner. This should include the collection of information on incidents but also information on accidents and serious incidents investigated under Regulation (EU) No 996/2010. Regulation 376/2014 sets out rules on reporting occurrences that would endanger an aircraft, its occupants and any other person, equipment or installation affecting aircraft operations, and the reporting of other relevant safety-related information in that context.

The EU ECR is built around the ECCAIRS taxonomy, which was originally based on the ICAO ADREP scheme. Several modifications and additions have been made to the taxonomy since the first version of the ECCAIRS system. Most reporting organisations have their own reporting systems, often using a taxonomy different from that of the ECR. However, Regulation 376/2014 imposes requirements on organisations related to reporting format and content[30]. Typically, the ECR taxonomy is much more detailed as it originates from the ICAO ADREP system, built to capture accidents and serious incidents, containing a lot of information that is usually available. EU Member States collect data at the national level and shall transfer these to the ECR. Organisations that report to the competent authorities in an EU Member State shall collect occurrences under both a mandatory and a voluntary reporting scheme. These two reporting schemes are different. Within the mandatory reporting scheme, data of occurrences that represent significant risk to safety and fall into categories as listed in Article 4(1) of EU Regulation 376/2014 shall be reported. Pursuant to Article 5 (1 & 2) of EU Regulation 376/2014, collected within the voluntary reporting scheme are details of occurrences that may not be captured in the mandatory reporting system and other safety-related information about actual or potential hazards to aviation safety.

NLR Air Safety Database

The NLR Air Safety Database contains detailed records of accidents and serious incidents that have occurred with aircraft and helicopters worldwide since 1970. Both commercial and non-commercial operations are included in the data. Only a few records of minor incidents are included. This database consists of data from a large number of reliable sources including, for instance, official international reporting systems (e.g. ICAO ADREP), Accident Investigation Bureaus (AIB) reports, insurance companies and aircraft manufacturers. These sources provide data for virtually all reported ATM-related accidents and serious incidents. The database also contains exposure data (e.g. number of flights) and arrival and departure data of commercial aircraft at airports worldwide.

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[30] Occurrence reports contained in an organisation's database and sent to the competent authority comply with format specifications that include: compatibility with the ECCAIRS software and the ADREP taxonomy and provision of mandatory data fields.

C.3.3 Data source query and data processing

EASA performed ECR query and the result was made available to be used exclusively for the purpose of the present study. For the query in the European Central Repository, the objective of the study was used to select the following criteria:

1. Occurrences in one of the EASA Member States, including the United Kingdom[31];
2. Period between 2013-2022 (included); the data for UK are included until 2020;
3. Fatigue of ATCOs is clearly indicated or reported as causal or contributing factor in the occurrence.

To apply selection criterion no. 3, a 'data query' was developed, which was comprised of a selection of keywords to capture a subset of occurrences from the data source. To apply the data query effectively, some knowledge and experience on how the information is organised and stored in the data source was needed. Relevant data can be sought through three different ways in the ECR:

1. Data search in 'Headlines';
2. Data search in 'Explanatory Factors';
3. Data search in 'Narratives'.

The keywords for use in this study were defined in consultation and agreed upon with EASA. For the data search in 'Headlines' and 'Narratives', the following keywords were used: 'air traffic controller' or 'ATCO' with 'fatigue', 'tired', 'alertness', 'wearied' or 'weariness'. Due to the multiple languages used in the ECR, the same combinations of words in French or Spanish were also used to capture the occurrences reported in those languages. The choice for using the keywords in these two languages in the data search was agreed upon with EASA. For the data search in 'Explanatory Factors', the following keyword combinations were searched: 'ATS personnel' or 'Air Traffic Controller' 'with 'Fatigue-rest/duty time', 'Fatigue-sleep deficit / disorder / disruption'. The keywords were available as predefined labels in the 'Explanatory Factor' data field and were only available in English; free text search was therefore not possible.

The same approach was followed for the data search in the NLR Air Safety Database. The combinations of keywords as used in the data search in 'Headlines' and in 'Narratives' in the ECR were applied in searching the relevant occurrences in the Narrative data field of the NLR Air Safety Database. The NLR Air Safety Database also included the possibility for data search in 'Explanatory Factors'. For this, the following keyword combinations were used in the data field 'Explanatory Factors': 'ATS organisation', 'ATS personnel' and 'Human fatigue' (these were available as predefined labels in the 'Explanatory Factor' data field; free text search was not possible).

Further details and results can be found in the study deliverable D-2.B.

[31] The United Kingdom is included in the selection due to the fact that before the Brexit (Britain exits EU) on 1 February 2020, the UK was a full member state of the EU and EASA.

C.4 Approach applied in the roster analysis

As part of the roster analysis, interviews were conducted with a sample of 16 ATSPs to obtain detailed insights on the rostering system and fatigue management practices. The points of contact of each ATSP coordinated the organisation of the interviews and invited the relevant interviewees, consisting of the members in charge of rostering, fatigue management and fatigue risk management. Other members of the ATSPs with relevant knowledge and involvement regarding the scope of the research study, such as human factors experts, occupational psychologists, and persons responsible for safety and operations, were welcome to attend the interviews. ATCOs were not consulted directly, as one of the aims of the interviews was to understand fatigue on an organisational level rather than on an individual level.

The methodology of the roster analysis is rooted in the current scientific knowledge of good practices regarding roster construction, incorporating guidance material stemming from various research on the topic. The process of analysing the roster sample is divided into three steps:

- Use of Dawson's Fatigue Likelihood Scoring Matrix, checking five criteria to obtain a weekly score between 0 and 40 for each roster.
- Expert analysis to assess how the rosters take into account scientific principles.
- Use of the FAID and SAFTE-FAST biomathematical models to obtain a maximum score on the level of sleepiness (KSS) for each shift in the roster.

At the end of these phases, several subsequent steps were carried out in order to select the sample of ATSPs that were invited to participate in the data collection phase of the project. The methodologies used for each of these steps are explained in the next sections. Further details and results can be found in the study deliverable D-2.C.2.

C.4.1 Use of Dawson's Fatigue Likelihood Scoring Matrix

The first phase in the analysis was the application of Dawson's Fatigue Likelihood Scoring Matrix to the roster sample. This matrix is used in the transport sector to generate weekly scores providing an indication of fatigue likelihood (McCulloch et al., 2007). This matrix is presented in the form of a table, as shown in Table B-1 enabling a weekly score to be generated for each of the five criteria presented. These five criteria can be used to predict sleep opportunities, and subsequent fatigue, within a roster.

Table C-1: Dawson's Fatigue Likelihood Scoring Matrix.

	0 points	1 point	2 points	4 points	8 points
Total hours over seven days	≤ 36 h	36.1h – 43.9h	44h – 47.9h	48h – 54.9h	≥ 55h
Longest duty	≤ 8h	8.1h – 9.9h	10h – 11.9h	12h – 13.9h	≥ 14h
Shortest rest between duties	≥ 16h	15.9h – 13h	12.9h – 10h	9.9h – 7.9h	≤ 8h
Night work over seven days	0h	0.1h – 8h	8.1h – 16h	16.1h – 23.9h	≥ 24h
Rest days	> 1 in seven days	≤ 1 in seven days	≤ 1 in 14 days	≤ 1 in 21 days	≤ 1 in 28 days

For each of these criteria, the further the roster practices deviate from Dawson's scientific recommendations, the higher the weekly score. The score for each criterion ranges from 0 to 8. The scores of each of the five criteria are summed to give an overall weekly score varying from 0 to 40.

The first criterion analysed is the total number of hours worked over a 7-day period. The greater the amount of time worked, the fewer opportunities remain for rest and sleep. The same applies to the second criterion, being the maximum length of a shift. If the length of the shift increases, there are less opportunities to sleep. Longer periods of wakefulness lead to fatigue in ATCOs and possibly a reduction in alertness during the shift. The third criterion represents the minimum rest time between two shifts. Dawson's fatigue likelihood scoring matrix recommends a minimum rest period of 16 hours to allow for a full night's sleep and recovery between shifts. The fourth criterion is the amount of night work, as defined as operational work between 2100 and 0900 local time (LT), over a 7-day period. This criterion goes beyond the analysis of night shifts, which are defined as shifts encroaching the night time between 0200 and 0459 local time: it considers early starts, late finishes and night shifts. All these shifts lead to a reduction in the opportunity for night sleep. Finally, the fifth criterion is the frequency of long breaks, i.e., the frequency of weekly rest periods. This rest time must, at the very least, include two nights' sleep with one non-working day in between. This rest time allows recovery from the fatigue and sleep deprivation accumulated over a period of work.

In order to categorise a week's exposure to risk within a roster, thresholds have been introduced. These thresholds were established to divide exposure to risk into three categories:

- 0-9: Low exposure to fatigue
- 10-14: Moderate exposure to fatigue
- 15-25: Significant exposure to fatigue

Based on the rosters analysed in the sample, it was chosen to use the threshold of 10-14. While all analysed rosters generated a risk that was considered acceptable, this categorization allowed for a nuanced perspective. Indeed, this method allowed for categorisation of the different levels of fatigue that can be found within this so-called acceptable level of fatigue. Thus, a cycle of 4 days ON – 4 days OFF (2 days from 0600 to 1800 local time, followed by 2 days from 1800 to 0600 local time, concluded by 4 rest days for a total of 48 operational hours) receives a score of 14 according to Dawson's fatigue likelihood scoring matrix. In view of the number of hours worked, the length of the shifts and the amount of night work, this cycle represents an exposure to risk that remains acceptable. A cycle of 4 days ON – 1 day OFF – 2 days ON (9-hour day shifts and a 8-hour night shift) receives a score of 10. Although this cycle contains night work, the organisation of working time and rest periods, as well as the length of shifts, mean that exposure to risk on this type of cycle is lower than on the previous example. These two cycles served as a basis for categorising the different weeks analysed using Dawson's fatigue likelihood scoring matrix.

This preliminary analysis using Dawson's matrix allowed an initial overview of fatigue risk exposure within the rosters, and it served as a solid basis for the second phase of this roster analysis.

C.4.2 Expert analysis and scientific principles of rostering

The expert analysis of rosters consisted of assessing rosters based on scientific knowledge on the effects of shift work on sleep and fatigue, and consortium expertise, as well as contextualising this assessment according to the characteristics of the rosters. The research that has been carried out in the field of shift work provides guidance for an initial assessment of the elements of fatigue in the rosters. Unlike the use of Dawson's Fatigue Likelihood Scoring Matrix, which assesses each week independently, this second stage analysed the rosters on a monthly level. This method allows to better observe the cumulative effect of work schedules on the risk of ATCO fatigue. The expert analysis focused on the evaluation of the application of scientific principles with respect to scheduling characteristics:

- Long shifts (exceeding 10 hours).
- Night shifts.
- Early shifts.

- Direction and speed of rotation of the shifts.
- Rest days.

The analysis also verified the organisation of consecutive shifts, the potential impact on work/life balance and workload between shifts in a roster. The scheduling characteristics and the scientific principles are described in more detail below.

Long shifts (exceeding 10 hours)

Scientific data unambiguously shows that longer shifts are associated with a higher likelihood of fatigue, a decrease in alertness and an increase in negative safety outcomes (e.g. Åkerstedt et al., 2008). Indeed, long shifts, i.e. shift lengths exceeding 10 hours, can be problematic in two ways:

- They prolong the period of wakefulness. This results in a high homeostatic sleep pressure, which will lead to reduced cognitive abilities. The effects workload exerts on fatigue are also amplified during long duties.
- They reduce the ATCO's opportunity for rest. Extending a shift equals shortening the periods of opportunity of rest.

It is therefore recommended to avoid long shifts, especially on the first day of a working cycle, but also after four consecutive working days. It is also advisable to avoid long consecutive shifts: combined with insufficient rest periods, they could lead to significant and lasting sleep loss over time.

Night shifts

Working at night and resting during the day is contrary to the human circadian rhythm. Some people might tolerate these shifts better, but contrary to what might be thought, people never fully adapt to night work. To mitigate the insufficient quantity and quality of daytime sleep caused by these shifts, consecutive night shifts should be avoided. These shifts must also be followed by a sufficiently long rest period to allow ATCOs to recover. Scientific consensus therefore considers that the amount of consecutive night shifts should be limited to two (Härmä et al., 2002). Regarding rest periods after a night shift, two precautions apply:

- After one night shift, it is recommended to schedule at least one night free of duty (i.e. no shift starting before 09:00 local time).
- After two or more shifts, it is recommended to schedule at least two nights free of duty (i.e. no shift starting before 09:00 local time). It is not advised to schedule a morning shift before the ATCO had 72 hours of rest.

Early shifts

Early shifts are associated with sleep deprivation over the previous night. Indeed, early shifts tend to require ATCOs to advance their wake-up time, subsequently forcing them to advance their bedtime as well. However, physiological (i.e. the body clock) and social reasons them in going to bed and falling asleep sufficiently early to get a full night's sleep. For this reason, it is a good practice to limit early shifts and, if possible, gradually stagger their start to allow better recovery between each shift.

Scientifically, it is not recommended to leave less than 24 hours between the start of early consecutive shift, in order to avoid morning shifts followed by afternoon shifts (Härmä et al., 2002). For example, avoid a morning shift starting at 06:00 local time and ending at 13:00 local time followed by a night shift starting at 23:00 local time on the same day. Despite the 10-hour gap of rest between both shifts, this configuration does not allow ATCOs to truly recover. The length and positioning of the rest period do not provide adequate sleep opportunities in terms of circadian rhythmicity. It is also advisable to adjust the number of consecutive early shifts according to the start time of the shift. Table B-2 summarises these best practices.

Table C-2: Recommendations for the number of consecutive shifts by start time.

Start of shift	Recommendation regarding the number of consecutive shifts
Between 04:00 and 06:00 local time	• Maximum 2 • Maximum 3 if the start of the shift is at least one hour later than the previous shift
Between 06:00 and 09:00 local time	• Maximum 3
Between 04:00 and 09:00 local time	• Maximum 4 shifts starting later (i.e. at least an hour's time difference) every day

Direction and speed of rotation of the shifts

The biological clock is characterised by a strong inertia to change and a natural tendency to shift progressively clockwise. It is therefore important to avoid slow rotations (i.e. more than three consecutive shifts with the same start time) that do not allow the biological clock to adjust completely. It is also important to avoid counter-clockwise rotations, which go against the body's natural tendency, subsequently causing sleep loss. Limiting transitions between different types of shifts within one same sequence is thus a good practice (Anund et al., 2015). Hence, based on the available science it is advised to:

- Use "fast" rotations rather than "slow" rotations (Mindell et al., 2012).
- Use clockwise rotations rather than counter-clockwise rotations.
- Limit transitions to one transition per cycle.
- Limit the end of the first shift following a morning sequence to 2300 local time (Åkerstedt & Folkard, 1995).

Rest days

It is important to differentiate between acute and chronic fatigue. Acute fatigue is the result of significant one-off sleep deprivation, whereas chronic fatigue is the result of lesser but repeated sleep deprivation. Although both represent risks, chronic fatigue is often underestimated. The best way to prevent chronic fatigue is to schedule regular rest periods that are as long as possible. Ideally, this should be several consecutive days. The organisation of shifts before and after these rest periods should also be designed to extend the rest period as far as possible. For example, scheduling an afternoon shift the day after a rest period leaves the morning free of duty. It is therefore advised to:

- Gather rest days rather than schedule isolated rest days. Rest periods should last for a minimum of two consecutive days.
- Avoid scheduling an evening shift before a rest period.
- Avoid scheduling a morning shift when resuming work after a rest period.
- In the case of an isolated rest day, schedule a morning shift before and an afternoon shift after, to benefit from two complete nights free of duty (Gander et al., 2008; Åkerstedt et al., 2000).

General scientific recommendations on roster organisation

Shift work or the atypical working hours of an ATCO are fundamentally in conflict with biological and social rhythms. To prevent the negative effects of this conflict, rosters should be as regular and stable as possible, with sufficient off-duty periods to allow for rest and social activities (Sallinen et al., 2010). In general, it is important to:

- Avoid consecutive sequences of night or afternoon shifts.
- Avoid scheduling more than five consecutive days. If six days must be scheduled, allow for at least 54 hours of rest (i.e., two consecutive nights, no shifts starting before 09:00 local time).
- Maintain a minimum of two evenings off per week.
- Avoid last-minute changes wherever possible.
- Balance the workload as much as possible:

- Between the work shifts of the same ATCO, but also
- Between ATCOs (Hanowski et al., 2007).

It is also important to be aware that the factors contributing to fatigue are not independent of one another as interactions between factors regularly occur. Night work and long shifts are particularly important in relation to the other factors, but each factor mentioned above is likely to interact negatively with the others. The presence of several factors can therefore have a cumulative effect on fatigue.

C.4.3 Use of biomathematical models

A quantitative approach based on the use of two biomathematical models was used to analyse the rosters. A biomathematical model (BMM) is a software program that predicts fatigue or alertness based on specific work schedules and estimated amounts of sleep. Biomathematical models were originally developed for the railway sector, but are nowadays used mainly by commercial airlines to build and evaluate crew schedules. Although not yet commonly used, BMMs could also be suitable tools for the conception and evaluation of ATCO schedules. The two models used and compared in this study are the SAFTE-FAST model[32] and the FAID model[33]. These are based on different theoretical grounds and show different sensitivity to various fatigue factors (for example, time of day and duty length). Therefore, these two models provided complementary approaches to assess the various scheduling practices used in the sample of rosters.

Measuring fatigue in scores: the Karolinska Sleepiness Scale
The two BMMs were calibrated using the same thresholds to allow comparisons between their results. The fatigue scale used in both models is the Karolinska Sleepiness Scale (KSS), with an acceptability limit for the level of fatigue set at the score of 7. Thus, any shift equal to or greater than 7 will be considered as a significantly fatiguing shift. Levels 7, 8 and 9 are therefore considered to be “critical” fatigue levels, as they exceed the set acceptability threshold. These fatigue levels are known to be associated with a significant decrease of performance and the occurrence of microsleeps (Kaida et al, 2006).

Setting up both models with identical parameters: commuting time and sleep
Commuting time and sleep time per day were set up in the same way for both BMMs. For commuting time, it was decided to use a maximum of 1 hour. In addition, it was decided to use the auto sleep function of both BMMs. This function, which is integrated into the software, defines sleep periods (main sleep and naps) based on the to be evaluated work schedules, and is based on validation studies performed by the BMM manufacturers.

Comparison of results
The use of two BMMs allowed the combination of a qualitative approach (expert analysis) and a quantitative approach during the roster analysis. The BMMs were used at the final stage of the roster analysis to enable an expert analysis to be carried out without any influence from the results of the BMMs. This method, combined with identical configuration of the two models, enabled several types of comparison to be made. The results of the BMMs were compared with the results of the expert analysis. These results were also used as a basis for comparison between the two models, SAFTE-FAST and FAID.

[32] https://www.saftefast.com/
[33] https://faidquantum.com/

C.5 Approach applied in the data collection campaigns

C.5.1 Introduction

The roster analysis was followed by a dedicated data collection campaign at six ATSPs with a total of 216 volunteer ATCOs, collecting a broad, subjective dataset to investigate ATCOs' day-to-day fatigue and sleep in relation with the various duty sequences. Objective data on ATCO fatigue and performance was collected during objective measurement campaigns at five ATSPs on 20 volunteer ATCOs during actual operational duties in the operations (OPS) room and control tower. The objectives of the latter campaign were to validate the subjective fatigue ratings obtained in the subjective data collection campaign, to analyse the effects of fatigue on ATCO performance, and to determine the feasibility for ATSPs to use objective measurement techniques to measure fatigue in real-time during the ATC operations.

C.5.2 Data collection with profile questionnaire

All ATCOs of the six ATSPs were invited to participate in the measurement campaign on a voluntary basis. Upon registering in the campaign, ATCOs first filled in an informed consent followed by a 'profile questionnaire' to collect demographic data. These data included age and gender (sex) of the participant, their commute habits, years of experience, type of qualification and the ATSP they work at, ratings of their work environment and technology support, ratings of the contribution of the system support and the working position to their workload, and questions regarding their fatigue and sleep.

C.5.3 Data collection with web-based app

The subjective data was collected using a dedicated smartphone application/web-based app developed by Welbees. Every day, over a minimum period of 10 consecutive days, the participating ATCOs were asked to fill out their daily events, including sleep, working sessions, stand-by duties, and non-operational duties, such as office duties, simulator sessions, medical checks, training sessions, on-the-job training sessions, and other forms of non-operational work. After each working session, ATCOs were asked to rate their perceived stress, workload, and fatigue, as well as to indicate any factors encountered during the working session from a predefined list of factors. Figure C-1 summarises the procedure for participating ATCOs.

Fatigue was assessed by means of a standardised scale, the Samn-Perelli scale ranging from 1 to 7. A value higher to 6 is associated with performance impairment. However, it is worth mentioning that the fatigue level threshold of 6 should not be considered as an absolute cut-off as slightly lower fatigue scores could be associated with impacts on ATCOs performance depending on the operational context. The data collected was analysed to provide a complete overview of the working conditions, the breaks timing and how much these can be expected to affect ATCOs' alertness and performance.

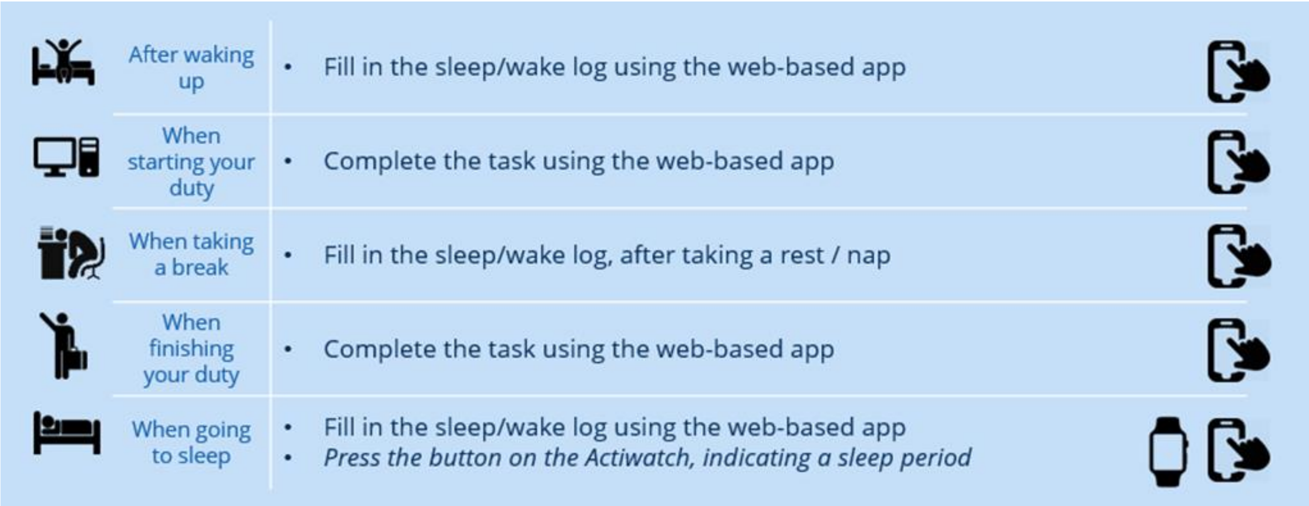

Figure C-1: Subjective measurement procedure for participating ATCOs.

C.5.4 Data collection with actigraphy

Actigraphy is an objective, non-intrusive and valid measure for sleep quantity and timing, using a wrist-worn accelerometer. The devices used to gather data on sleep quantity and timing during the subjective data collection campaign were the MotionWatch8 and the Philips Respironics AW2. Based on the measured activity of the participants, a dedicated algorithm calculated their sleep and wake times. The ATCOs in the six participating ATSPs were invited to wear the actigraphs on a voluntary basis, in order to complement and validate the subjective sleep data they registered in the app. In total, 15 actigraphs were provided to each of the participating ATSPs for further distribution to these volunteering ATCOs. Participants were asked to continuously wear (both on and off duty) the actigraph for a period of 10 consecutive days to provide enough sleep data in relation to the different shifts (all shift types included).

C.5.5 Continuous eye tracking and PVT data collection

Five ATSPs were involved in the objective measurements aimed at validating the subjective data collection campaign and assessing the feasibility of using continuous eye tracking measurements in the OPS room. The designated Point of Contact of these ATSPs was contacted, and a meeting was set-up to explain the purpose of the measurements and practicalities concerned. During these meetings, it was also discussed how any potential effect of the measurements on the normal operational traffic handling could be mitigated. Furthermore, it was explained that the study team was seeking at least four voluntary participating ATCOs to be monitored during the shifts identified as fatigue hotspots as a result of the roster analysis (see section Annex C.4). It was chosen to use the shifts which were deemed most fatiguing because this would lead to a larger variation in fatigue within the shift, and would therefore be more useful for the validation purpose. Furthermore, using the pre-defined fatigue hotspots based on the roster analysis (instead of waiting for the outcomes of the subjective measurement campaign) made it possible to organise the measurements with the ATSPs in time, so that they could be finalised within the timeframe of this study.

After agreeing consent, the participating ATCOs had to fill in a baseline questionnaire concerning demographics, experience, the quality of the workplace facilities, and habitual sleep/fatigue before the start of the shift. A researcher conducted a briefing next, after which the participants were instructed to practice the PVT once. The eye-trackers were strategically positioned at two workstations, and recorded data throughout the shift. The subjective fatigue and workload ratings were collected approximately every hour. Upon completion of their duties, ATCOs were asked to provide their final subjective ratings, together with the post-duty PVT task. Subjective fatigue was assessed by means of both the Karolinska Sleepiness Scale (KSS) (Åkerstedt & Gillberg,

1990) and the Samn-Perelli Fatigue Scale (SP) (Samn & Perelli, 1982). Workload was assessed by means of the validated Rating Scale Mental Effort (RSME) (Zijlstra, 1993) and the Instantaneous Self-Assessment (ISA) (Legatt, 2023).

Eye tracking was used to assess fatigue objectively, by means of the outcome measures blink duration, blink frequency, and the Percentage of Eyelid Closure (PERCLOS, Abe et al., 2023). Eye tracking was also used for objective workload assessment by means of the indicators blink frequency and blink duration (Benetto et al., 2011). For the measurements at the ATSPs two types of SmartEye™ eye trackers were used, the SmartEye XO and the SmartEye Pro. These devices use optical tracking supported by infrared light. By means of corneal reflection, they monitor pupil size, pupil shape and the position of the eyelids in real-time, which the software computes into the different outcomes measures.

The 3-minute Psychomotor Vigilance Task (PVT) performance measure was used to assess the effect of fatigue in ATCOs. The PVT was offered to the ATCOs using a dedicated PVT app on a standalone tablet, directly before and after the shift.

The whole objective measurement procedure is shown in Figure C-2. The data was collected and processed in accordance with data protection legislation. After the measurements at each ATSP, all data was anonymised, digitalised, and saved on a secured network. Next, all data acquired was matched, merged, cleaned and processed before the different outcome measures were determined. Subsequently, the statistical analyses were performed. All demographic, function and shift related information acquired at baseline was analysed using descriptive statistics. In order to find out if, and to what extent, the subjective ratings were associated with the chosen objective outcome measures, the data was analysed using Spearman correlations.

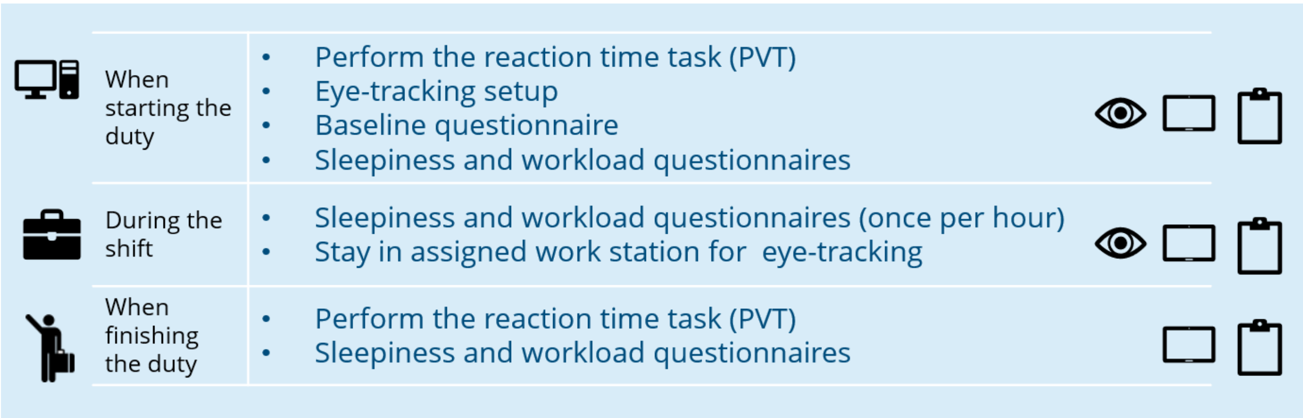

Figure C-2: Objective measurement procedure for participating ATCOs.

Annex D Detailed results

D.1 Results of findings from the literature review

Table D-1: Comparison between main findings of the ATCO fatigue-related literature review with the literature in other domains. Note that table is split in two parts.

Topic	Main Findings				
	ATCOs	**Aircrew**	**Health care professionals**	**Energy operators**	**Rail operators**
Prevalence	50-55% feels tired during work. ±70% indicates to have dozed off during the past year (US & Asia).	Estimated prevalence of 50-80% based on subjective cross-sectional data of European aircrew	Unknown	Unknown	Severe sleepiness in 50% of the night shifts and 15% of the morning shifts.
Causes	<u>Shifts</u>: time of day, shift length (time on task), type of shift (night or morning shift) <u>Shift schedule:</u> rest period between shifts/shift cycles, shift pattern (e.g. counter clockwise rotation), number of night shifts, number of shifts in a row, pre-duty sleep, breaks (timing, frequency and length), quick turnarounds <u>Workload</u>: Type of work, time on task, high or low workload, stress, task demand, traffic load. <u>Work environment:</u> heat, noise, light, humidity, rest facilities <u>Non-work</u>: Sleep disorders, work-home balance, Individual factors (personality characteristics, health, age, chronotype)	- Long Time on Task - Time since awake - Poor Pre-duty Sleep - Phase of Circadian Cycle (night, early morning) - High Workload - Shift Scheduling - Health related aspects: medication, hangover, Obstructive Sleep Apnea (OSA), Sleep disorders, depression, life stresses	- Long continuous duty hours - Reduced opportunities for naps while on duty - Shift work	- Shift work - Transitions between schedules - Periodic overtime - Mental and physical demands combined with undynamic environment - Increased workload - Commute to ship/platform - Environmental conditions (such as noise, vibrations, and light)	- Type of shift (night shift, morning shifts) - Irregular shift systems - Varying break lengths - Long working hours - Insufficient sleep - Large variations in (mental) workload - long periods of low activity / monotonous work. High level of automation - Time-on-task - Poor working environment

Topic	Main Findings				
Effects	- No recent evidence for association with errors/incidents - Performance (speed, communication) - Situational awareness	- Sleepiness and impaired alertness - Reduction in speed and accuracy of performance - Lapses of attention and vigilance - Delayed reactions - Impaired logical reasoning and decision-making - Reduced ability to assess risk - Reduced situational awareness - Low motivation for optional activities	- Sleepiness and microsleeps during night shifts - Errors in routine tasks at night - Impairments in physical, cognitive, and emotional functioning.	- Decreased performance in tasks - Changes in emotional state - Diminished ability to communicate effectively - Loss of 'big picture' situational awareness - Loss of attention across displays - Difficulty concentrating on tasks - Lapses in attention	- Increased accident risk - Impairments in attention, cognitive ability, and judgment - Dangerous behaviours such as speeding
Mitigation	- Napping during night shifts - Pre-duty video game play - Shift schedules tailored to preferences of population - Longer recovery periods in between shifts	- Usage of Biomathematical Models - Fatigue Risk Management - Pre-duty napping - Optimal sleep hygiene - Brief naps in the cockpit - Stimulation of healthy lifestyle - Treatment of OSA, sleep disorders.	- Optimal shift scheduling - Pre-duty naps - Power naps during night duty - Education to stimulate sleep hygiene and healthy life style	- Limiting work hours - Implementing rest breaks - Predictable shift schedules - Minimisation of periodic overtime - Suitable transitions between shift types - Training / education	- Optimal scheduling - usage of BMM - Avoiding compressed work weeks - Sufficient frequency and duration of breaks - Compensation of sleep loss - Individual sleep monitoring and feedback - Higher automation / more activated tasks - Napping - Promoting healthy sleep during non-work - Organisational learning - Optimal staffing levels - Technical solutions - Monitoring operator state

Table D-2: Overview of the main gaps identified, including the appraisal of the most relevant gaps (X) in the context of this study as identified by EASA and Consortium experts.

Topic	Gap identified	Most relevant
Prevalence	More studies needed using validated outcome measures (both subjective and objective)	
	Real-time measurements	X
	Study different types of ATSPs and different ATCO positions and functions	X
	Usage of large(r) samples of participants within European ATCOs that are representative for the target population	
Causes	ATSP specific work schedules (within Europe), and it's characteristics (e.g. shift length, rest days, shift rotation etc.)	X
	Type of scheduling (e.g. individual/flexible vs. fixed rosters, possibility to swap shifts).	
	Pre duty sleep (length, quality) / time since awake	
	Boredom / inactivity during work (cognitive load). E.g. as a result of single person ATC operations.	X
	Influence of technology and/or work practices	X
	Non-work related factors such as	
	- health	X
	- lifestyle	
	- sleep disorders and/or Obstructive Sleep Apnea (OSA)	
	- work-home balance	
	- personality	
	- age	X
	- chronotype	
	- circadian flexibility	
Effects	Specific types of performance (e.g. communication, decision making, problem solving)	X
	Determination of tasks that are sensitive to fatigue	
	Association with errors / incidents	
	Association of (cumulative) fatigue with health and wellbeing	
Mitigation	Optimal work-rest patterns / schedules	X
	Optimal efficacy of breaks (length, timing activity) and optimal rest facilities	X
	Optimal watch scheduling / seat rotation within a shift	
	Optimal working environment (e.g. light, noise)	
	Education on sleep hygiene / habits / lifestyle	
	Usage of planning tools (software) to develop ergonomic shift schedules	X
	Usage of biomathematical fatigue models to pro-actively prevent fatigue hotspots	X
	Usage of a fatigue reporting system	
	Usage of technology to aid, monitor or pro-actively detect ATCOs (fatigue)	
	Strategic caffeine / nutrition usage	

D.2 Detailed results on eight mandatory rostering elements

The results from the ATSP survey showed the following changes in the roster elements between 2017 and 2023:

- **Maximum consecutive working days with duty**: In 2017, the average maximum consecutive working days with duty were 5.9 days for the ATSPs providing services at ACCs and 6.0 days for ATSPs providing services at aerodromes only. In 2023, the average maximum consecutive working days with duty were 5.9 days for the ATSPs providing services at ACCs and 5.8 days for ATSPs providing services at aerodromes only. These elements indicate that there is no significant difference in the average maximum consecutive working days with duty whether the ATSP provides services at ACCs or at aerodromes and that the average is around 5.9 days. The average working days with duty have not changed with the introduction of Regulation (EU) 2017/373.
- **Maximum hours per duty period**: The average maximum hours per duty period was 9.2 hours for ATSPs providing services at ACCs in 2017 as well as in 2023. For ATSPs providing services at aerodromes only, the average maximum hours per duty period increased from 10.1 hours in 2017 to 10.5 hours in 2023. The average maximum hours per duty period was higher for aerodrome ATSPs than for ATSPs providing services at ACCs for both 2017 and 2023.
- **Maximum time providing air traffic control service without breaks**: In 2017 the average maximum time providing air traffic control service without breaks was 107 minutes for ATCOs working at ACCs and 146 minutes for ATCOs working at aerodromes only. In 2023 the average maximum time providing air traffic control service without breaks was 90 minutes for ATCOs working at ACCs and 154 minutes for ATCOs working at aerodromes. The maximum time providing services without breaks was higher for ATSPs providing services at aerodromes compared to those providing services at ACCs in 2017 and in 2023. While the average maximum time has decreased with 16% between 2017 and 2023 for ATCOs working at ACCs, it has increased with 5% for ATCOs working at aerodromes.
- **The ratio of duty periods to breaks when providing air traffic control service**: In 2017, the average duty time was 0.67 of the total working time for both ACCs and aerodromes, i.e., a ratio of duty periods to breaks of approximately 2:1. In 2023, the average duty time was 0.69 of the total time providing air traffic control services for ATCOs working at ACCs and 0.72 for ATCOs working at the aerodromes, i.e., a ratio of duty periods to breaks of approximately 2:1.
- **Minimum duration of rest periods**: In 2017, the average minimum duration of rest periods was 10.4 hours for ATCOs at ACCs and 11.6 hours for ATCOs at aerodromes. In 2023, the average minimum duration of the rest periods was 11.6 hours for ATCOs at ACCs and 12.0 hours for ATCOs at aerodromes. The figures indicate that in 2017 and 2023 the average minimum duration of the rest period was lower for ATCOs at ACCs than for ATCOs at aerodromes. The average minimum duration increased between 2017 and 2023 for both categories of ATCOs, with a 1.2 hours' increase for ATCOs at ACCs. This reduces the difference between ATCOs at aerodromes and ATCOs at ACCs.
- **Maximum consecutive duty periods encroaching night time**: In 2017, the average maximum consecutive duty periods encroaching the night time were almost the same for both ATCOs categories, i.e., 2.0 days for ATCOs working at ACCs and 2.1 days for ATCOs working at aerodromes. In 2023, the average maximum consecutive duty periods encroaching the night time had increased to 2.3 days for ATCOs working at ACCs and 2.9 days for ATCOs working at aerodromes.
- **Minimum rest period after a duty period encroaching the night time**: In 2017 and 2023 the average minimum rest period after a duty period encroaching the night time was higher for ATSPs providing services at ACCs than for ATSPs providing services at aerodrome only. This difference increased between 2017 and 2023. For ATSPs providing services at ACCs, the average rest period increased from 19.9 hours in 2017 to 22.5 hours in 2023. For ATSPs providing services at aerodromes only, the average minimum rest period after a duty period encroaching the night time decreased from 18.4 hours in 2017 to 17.8 hours in 2023.

- **Minimum rest periods within a roster cycle**: The average minimum number of rest periods within a roster cycle increased between 2017 and 2023 for both categories of ATSPs For ATSPs providing services at ACCs, the average minimum number of rest periods within a roster cycle increased from 2.8 in 2017 to 3.7 in 2023. For ATSPs providing services at aerodromes only, the average minimum number of rest periods within a roster cycle increased from 2.7 in 2017 to 3.7 in 2023.

Differences between 2017 and 2023
The implementation of the ATCO fatigue-related regulations seemed to have resulted in the following potential improvements of ATCO working conditions:
- A decrease of the average maximum time providing air traffic control service without breaks for ATCOs providing services at ACCs (-17 minutes between 2017 and 2023).
- An increase of the average duration of rest periods for both categories of ATCOs (+ 1.2 hour for ACCs, +0.4 hour for aerodromes).
- An increase of the average minimum rest period after a duty period encroaching the night time for ATCOs at ACCs (+ 2.6 hours between 2017 and 2023).
- An increase of the minimum number of rest periods within a roster cycle for both categories of ATCOs (+1 hour between 2017 and 2023).

However, the implementation of ATCO fatigue-related regulations also seemed to have led to the following potential deterioration of ATCO working conditions:
- An increase of the average maximum hours per duty period for ATCOs providing services at aerodromes (+ 24 minutes between 2017 and 2023).
- An increase of the average maximum time providing air traffic control service without breaks ATCOs working at aerodromes (+8 minutes between 2017 and 2023).
- An increase of the average maximum consecutive duty periods encroaching the for both categories of ATCOs (+0.3 days for ACCs, +0.8 days for aerodromes).
- A decrease of the average minimum rest period after a duty period encroaching the night time for ATCOs at aerodromes (- 36 minutes between 2017 and 2023).

The implementation of the ATCO fatigue regulatory requirements related to the rostering system did not seem to have changed the average maximum consecutive working days with duty and the ratio of duty periods to breaks for both categories of ATCOs.

Differences between ATSPs providing services at ACCs and ATSPs providing services at aerodromes only
The survey results indicated no significant differences between ATSPs providing services at ACCs and ATSPs providing services at aerodromes for:
- The average maximum consecutive working days with duty.
- The average ratio of duty periods to breaks when providing air traffic control service.
- The average minimum rest periods within a roster cycle.

However, the average figures differed between ATSPs providing services at ACCs and those providing services at aerodromes in the 5 other elements of the rostering system prescribed in the ATCO fatigue regulatory requirements. Compared to ATCOs providing services at ACCs, ATCOs providing services at aerodromes have:
- A longer average maximum hours per duty period (+1.3 hours in 2023).
- A longer average maximum time providing air traffic control service without breaks (+ 64 minutes in 2023).
- A longer average maximum consecutive duty periods encroaching the night time (+ 0.6 days in 2023).

- A shorter average minimum rest period after a duty period encroaching the night time (- 4.7 hours in 2023).
- A longer average duration of rest periods (+0.4 hours in 2023).

The analysis focussed on the average figures for the elements of the rostering systems. For all elements, the results show a variation and broad range of applied values. In general, the variation for ATCOs at ACCs is less than the variation for ATCOs at aerodromes. Between 2017 and 2023 the variation in the elements of the rostering systems increased or remained the same except for the maximum consecutive working days with duty where the variation decreased. This demonstrates that the rostering systems and the maximum and minimum values of the roster elements are determined by national regulations, local conditions and practices. Therefore, they are not identical across the EASA Member States.

Annex E Management of ATCO fatigue in the operational environment

E.1 Good practices for the use of biomathematical models in the roster design

This section describes good practices for the usage of biomathematical models (BMMs) as part of the design of ATCO rosters. ATSPs are advised to consider the following points when implementation the use of a BMM:

- Model users should receive training on fatigue and fatigue management.
- Model users should be educated on the advantages and limitations of BMMs in order to avoid simplistic interpretations of the numbers provided by the models.
- Thresholds should be validated for the specific activities of the organisation. Biomathematical models should be used primarily for comparing different work schedules.
- A conservative approach should be used if using individual parameters (e.g., chronotype 'evening type' for evaluating early shifts).
- Fatigue models are only one tool amongst many other methods which can be used as part of the FRMS. Additional strategies to identify and manage fatigue shall also be considered to complement the use of BMMs.

E.2 Good practices on occurrence investigation of fatigue and fatigue factors

This section provides good practices to support ATSPs in investigating the role of fatigue in reported occurrences. To identify and assess any potential contribution of fatigue in the occurrence, the following step-by-step approach can be applied:

<u>Step 1: Interview with the ATCO to estimate their sleep quantity and quality</u>

In this step, one should:

- Determine if the ATCO had acute or chronic sleep loss by assessing sleep-wake patterns for at least 72 hours prior to the occurrence.
- Identify any disturbed or fragmented sleep.
- Identify any sleep disorders, health issues or medication.

<u>Step 2: Analyse the actual roster and potential deviations to determine the potential contribution of the roster features</u>

In this analysis, one should take into account:

- Time of the occurrence.
- Type of shift.
- Length of the duty before the occurrence.
- Number of consecutive shifts.
- Rest duration before the shift.
- Rest days in the last 7 days.
- Roster direction (clockwise/anticlockwise).
- Presence of shift swap.

If available, a biomathematical model can be used to analyse the schedule of the ATCO prior the occurrence.

<u>Step 3: Collect evidence to determine changes in performance potentially related to fatigue</u>

This step can be conducted by means of e.g. an interview with the ATCO, colleagues or the supervisor. The available evidence can be used to determine whether the ATCOs performance was deteriorating prior to the occurrence, for example by addressing these questions in the analysis:

- Did the ATCO overlook or skip tasks or parts of tasks?
- Did the ATCO focus on one task to the exclusion of more important tasks or information?
- Was there evidence of delayed responses to relevant information or unresponsiveness?
- Was there any evidence of poor communication or cooperation?
- Was there evidence of impaired decision-making or an inability to adapt behaviour to accommodate new information?

Step 4: Identify and implement fatigue risk mitigation measures.
In case fatigue has been established as a contributing factor to the occurrence, mitigations measures should be identified and considered for implementation. These mitigations measures should be defined on the basis of existing data:

- Literature review and scientific studies.
- Experience within the ATSP.
- Other ATSPs' experience.

These mitigations measures should cover different levels:

- Definition of soft rules in the rostering.
- Training of the rostering staff.
- Training of ATCOs on sleep and fatigue management.
- Development and implementation of formal procedures that serve to compensate for the impaired performance and reduce the potential for an occurrence.
- Use of fatigue-prevention strategies, e.g., task rotations, supervisory checks, breaks, napping.

Evaluating and monitoring the effectiveness of mitigation measures is required through the implementation of relevant indicators, as mentioned in the section on proactive processes of FRMS.

E.3 Good practices for fatigue reporting

This section provides good practices for the reporting of an ATCO fatigue-related (safety) occurrence and the use of fatigue reports in the context of FRMS.

1. Report causal and contributing factors.
Occurrence reports should include the essential basic information with causal and contributing factors.

- Specify at least the date and time of occurrence, the phase of flight, controller position.
- Specify any potential causes.
- Specify any potential effects on ATCO performance, task execution, errors, and/or (unsafe) outcomes.
- Provide contextual information on the roster related and non-roster related fatigue factors.
- Provide details on the ATCO work situation such as: shift, work schedule, shift / duty start and end time, (rest) breaks used, rostering schedule, previous duty times, sleep duration and quality, perceived workload/stress.
- Provide contextual information on the work condition: traffic complexity, traffic volume, traffic density, monotonous traffic situation, meteorological conditions, unexpected situations, coordination with colleagues, issues with tools/technology.
- The nature of the report should be recorded as either 'voluntary' or 'mandatory'.

2. Process the occurrence details according to the ECCAIRS taxonomy.
For the sake of data consistency, it is recommended that ATSPs process detailed information according to the standard taxonomy of ECCAIRS. Information retrieved from detailed reports (e.g. the narrative) should be

completed in the data fields of the ECR. Apply the ECCAIRS taxonomy, for instance Explanatory Factors taxonomy related to fatigue and workload as applicable (refer to ECCAIRS Explanatory Factors taxonomy).

3. Use a common language in occurrence reporting
It is recommended that ATSPs use a common language, e.g. one of three ICAO working languages in Europe (English, French and Spanish), in the occurrence reporting system. It is noted that Regulation (EU) 376/2014 does not restrict the use of native language.

4. Implement good practices on the usage of fatigue reports
To encourage an ongoing commitment by staff to report fatigue threats, the ATSP can implement the following good practices:

- Have clear processes for reporting fatigue threats.
- Be clear that the organisation expects ATCOs to report fatigue threats, with explanation of why this is important to the organization and ATCOs, and how data will be protected.
- Establish a process for what to do when ATCOs considers themselves too fatigued to perform safety critical tasks to an acceptable standard.
- Identify the implications for individuals of submitting a fatigue hazard report.
- Identify how the organisation will respond to reports of fatigue threats, including acknowledging receipt of reports and providing feedback to individuals who have reported.
- Take appropriate actions in response to fatigue reports consistent with stated policy.
- Maintain the integrity of the safety reporting system and reporter confidentiality.
- Provide feedback to ATCOs on changes made in response to identified fatigue threats.
- Evaluating and monitoring the effectiveness of applicated mitigation measures.

E.4 Fatigue data collection techniques

Fatigue and workload can be assessed in numerous ways, both objectively and subjectively. Some of the most widely used and validated methods of assessing fatigue, workload and the potential impact on performance are listed in the tables below.

E.4.1 Assessing fatigue

Objective sleepiness or fatigue is often measured by performance measures, such as the Psychomotor Vigilance Task (PVT). It measures sustained attention based on a simple reaction time task. A decrease in response speed of the performance measure is associated with an increase in fatigue and sleepiness (Dinges & Powell, 1985), yet as it assessed vigilance it may also be a measure for drowsiness. Furthermore, the subjective perception of fatigue is often used to evaluate fatigue through self-reports. Common methods for assessing subjective fatigue are the nine-point Karolinska Sleepiness Scale (KSS) and the seven-point Samn-Perelli scale (Åkerstedt & Gillberg, 1990; Göker, 2018; Samn & Perelli, 1982). Both methods have been associated with sleep loss and the performance of flight crew (Gander et al., 2013; Thomas et al., 2015). It is however expected that it is difficult to assess the effect of technology on fatigue by means of real-time simulations, due to the limitations of a simulation experiment and due to the erratic course of fatigue / drowsiness in the course of a day.

Table E-1: The Samn-Perelli scale.

Level	Description
1	Fully alert, wide awake
2	Very lively, responsive but not at peak
3	Okay, somewhat fresh
4	A little tired, let down
5	Moderately tired, let down
6	Extremely tired, very difficult to concentrate
7	Completely exhausted, unable to function effectively

Table E-2: The Karolinska Sleepiness Scale.

Level	Description
1	Extremely alert
2	Very alert
3	Alert
4	Rather alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, but no effort to keep awake
8	Sleepy, but some effort to keep awake
9	Very sleepy, great effort to keep awake, fighting sleep

E.4.2 Assessing workload

Studies frequently take into account various workload dimensions to subjectively measure workload. For instance, one of the most widely used subjective measure is the NASA-TLX, created by NASA in the 80s. The NASA-TLX breaks down workload into several key dimensions, including cognitive demands, physical demands, temporal time demands, evaluation of self-performance, effort, and feelings of frustration. Typically, the NASA-TLX is administered post-task, allowing participants to retrospectively rate their workload (Hart & Staveland, 1988; Yazgan et al., 2021). However, subjective assessments could also be conducted throughout a task, but are often limited to one dimension, with participants providing workload ratings at brief intervals throughout the task. For instance, the validated Instantaneous Self-Assessment (ISA), developed by the National Air Traffic Service (NATS) in the UK to assess the mental workload of ATCOs, where participants self-rate their workload on a scale of 1 (under-utilised) to 5 (excessive) (Di Flumeri et al., 2015; Rodgers, 2017).

In addition, psycho-physiological measurements are used in research settings to derive an objective indicator for workload. Examples include Heart Rate Variability (Delliaux, 2019) and eye tracking measurements, e.g. blink frequency (Zheng et al., 2012) and pupillometry (Krejtz, 2018). These measurements however only provide insights in trends (workload increase/decrease) relative to a baseline measurement. Workload measurements are performed in human in the loop simulations evaluating new ATM technologies mainly but are also used for workload modelling.

E.4.3 Summary of methods

The tables below present available methods which can be used in the context of fatigue data collection. Each method is assessed against its validity, sensitivity and applicability in real setting situations. Some precautions of use are also mentioned.

Table E-3: Main available methods used in fatigue data collections.

	Fatigue scales: SP and KSS
What is measured	Current level of experienced fatigue.
Validity/sensitivity	KSS and SP have been validated against objective measurements in several studies. In the present study subjective ratings of fatigue have been found to be correlated with eye tracking measurement.
Required expertise	Data collection does not require much expertise but data analysis should be based on appropriate statistical analysis tests which need expertise.
Applicability on the field	Very applicable, not invasive.
Limits and precaution of use	Require large samples (> 30 participants) to provide significant statistical results. Requires a strong adhesion from the ATCOs (a large communication phase is needed). Could be biased by non-fatigue-related factors (job satisfaction, motivation…). Fatigue scales have not been designed to be used retrospectively.

	Sleep diaries
What is measured	Reported quantity of sleep are correlated with actigraphy.
Validity/sensitivity	Very high, well validated with actigraphy campaigns.
Required expertise	Low
Applicability on the field	Very applicable.
Limits and precaution of use	Need appropriate statistical analysis, especially when validating with actigraphy data.

	Workload scales: NASA-TLX, ISA and RSME
What is measured	Measure the effort (mental, physical or sensorial) an ATCO is experiencing.
Validity/sensitivity	Very high.
Required expertise	Data collection does not require much expertise but data analysis should be based on appropriate statistical analysis tests which need expertise.
Applicability on the field	Very applicable, not invasive.
Limits and precaution of use	Need appropriate statistical analysis.

	Actigraphy
What is measured	Objective measure of sleep quantity.
Validity/sensitivity	Well validated against “gold measure” (polysomnography).
Required expertise	Required expertise to analyse the data.
Applicability on the field	Not invasive and moderately applicable as it requires to wear a device for several consecutive days.
Limits and precaution of use	The equipment is expensive and cannot be used on a very large scale.

	PVT
What is measured	Performance (reaction time, reaction speed, lapses).
Validity/sensitivity	Have been extensively used in laboratory and field settings, good validity.
Required expertise	Required expertise to analyse the data.
Applicability on the field	Can only be administered during ATCOs break.
Limits and precaution of use	Requires the use of a standard equipment (laptop, tablet, smartphone) to avoid that the measured reaction time is not influenced by the processing capacity of the personal device.

	Eye tracking
What is measured	Measures (percentual) eyelid closure, and blinks duration and frequency.
Validity/sensitivity	Well validated in lab settings and (driving) simulators.
Required expertise	Expertise required for both set-up and analysis.
Applicability on the field	Remote eye trackers are not invasive and used throughout shifts (fixed CWP).
Limits and precaution of use	Requires an extensive set-up time, and calibration is advised. For continuous measurements ATCOs need to remain on same CWP. Less useful for tower positions. Future developments (e.g. camera based eye tracking) could be promising.

	Electro-encephalogram (EEG)
What is measured	Measures brain activation. Considered as the “golden” standard to measure the level of alertness.
Validity/sensitivity	Well validated, very sensitive to fast variations in alertness.
Required expertise	Requires costly equipment and expertise to calibrate, collect and analyse the data.
Applicability on the field	Invasive (requires the placement of electrodes.
Limits and precaution of use	Individual practical variance (e.g. because hair) and electrodes might hinder normal ‘degrees of freedom’ in work. Less intrusive (standalone, one channel) devices that are available lack validity/reliability up to now.

	fNIRS (functional near-infrared spectroscopy)
What is measured	Neuroimaging technique that measures changes in blood oxygenation levels in the brain, which can be associated with changes in cognitive and physiological processes indicating fatigue and drowsiness.
Validity/sensitivity	High.
Required expertise	Equipment is costly, expertise needed to prepare, collect and analyse the data.
Applicability on the field	Moderately invasive (limited number of electrodes on the side of the head).
Limits and precaution of use	Needs to be validated further, not yet test in ops room settings.

	Speech
What is measured	Fatigue and stress detection through different voice parameters.
Validity/sensitivity	Limited information available about validity.
Required expertise	Could be easy to interpret (in real-time) with a good user interface.
Applicability on the field	Non-intrusive, relatively cheap.
Limits and precaution of use	Needs to be validated further, especially in ops rooms settings.

E.5 Validation of fatigue-related training and education

In training design it is of importance to include both scientific principles as the needs of the personnel. A Training Needs Analysis (TNA) can provide insight into the trainees, their starting point and the intended end goal. It is of importance that fatigue-related training does include the scientific-based topics as described by ICAO in both DOC 9966 (Manual for the Oversight of Fatigue Management Approaches) and the ICAO Fatigue Management Guide for Air Traffic Service Providers (first edition 2016):

1. The need for sleep
2. Sleep loss and recovery
3. Circadian Effects on Sleep and Performance
4. The influence of workload

These topics can then be further specified and added to, depending on the needs of the ATCOs involved. We would encourage ATCOs to be involved in training design, alongside Learning and Development specialists and Fatigue experts to ensure that all facets of the training and training design are covered. Once the training has been implemented, it is important to use a validated procedure to evaluate effectiveness. There are many different models for training evaluation of which Kirkpatrick is the most well-known. Kirkpatrick (1983, 1996) developed a model with 4 stages identifying participant reactions (level 1), changes in knowledge skills and attitudes (level 2), changes in job behaviour (level 3) and organisational results (level 4). The strength of this model lies in the fact it is easy to comprehend and makes sense to organisations (Tamkin et al., 2002). There are also several models that claim to enhance Kirkpatrick's original model of training evaluation. Hamlin (1974) for instance splits Kirkpatrick's' level 4 in to 'organisation' and 'ultimate value' (financial effects) to create a five-level model. More recently an approach was developed by Indiana university (Molenda et al., 1996) that is based on six strata. It extends on Kirkpatrick's model by adding a first stratum that includes training volume and levels and a sixth stratum that examines social impact. Tamkin et al. (2022) give a comprehensive overview of the different training evaluation models that can be used as a basis to develop a training evaluation methodology. They conclude that while a huge amount of different terminology is used there is also a lot of overlap between the models and strategies did not change much in the 40 years prior to their writing. Secondly, they conclude that there really is no one-way to evaluate training as it always requires integration of the training purpose, the evaluation purpose, the audience for the evaluation, measurements taken and time framework. The NLR-developed Training Evaluation Method follows the Kirkpatrick principles of training evaluation but has added a step that evaluates training design. It encompasses a step-by-step evaluation of the design, execution, training goals, training transfer and evaluation. Each part is divided into several subjects that are evaluated separately to result in the final conclusion. Several different research methods are used, including desk research, student evaluation, instructor evaluation and work-floor evaluation.

Regardless of the evaluation approach used, it is important to define Key Performance Indicators (KPIs) with both management and professionals prior to implementation. As we have learnt from the training evaluation models these KPIs should cover all aspects of training, so not only if the learning objectives have been achieved but also to what extent the trainer was competent and the general experience of both students and trainer(s). When evaluating learning goals it is recommended to look at both the theoretical and the practical goals. How to measure these depends very much on the training itself. In some cases theoretical knowledge can be measured by examination but it is of importance to develop a number of tools and use a combination of evaluation, observation and data analysis. Table E-4 includes a list of possible KPIs that can be used in training evaluation.

Table E-4: Example of possible KPIs for training evaluation.

KPI	Description
Trainer competence	To what extent was the trainer competent? • Teaching skills • Coaching skills (if relevant) • Knowledge of the subject
Trainer experience	How does the trainer rate the training on the following subjects? • Teaching • Logistics • Training content • Training materials
Student experience	How do students rate the training on the following subjects? • Teaching • Logistics • Training content and materials
Learning objectives	To what extent have the learning objectives been reached? • Achievement of theoretical learning objectives • Retention of theoretical learning objectives • Achievement of practical learning objectives • Retention of practical learning objectives (learning objectives should be formulated prior to training development)

E.6 Required elements for FRMS documentation

The FRMS documentation should describe all elements of the FRMS and provide a record of FRMS activities along with any changes to the FRMS. The documentation of required information can be centralised in an FRMS manual or may be integrated into the ATSP's Safety Management System (SMS) manual. The documentation needs to be accessible to all personnel within the organisation. The elements that should be included in the FRMS documentation of ATSPs are those defined in ICAO Doc 9966:

- FRMS policy and objectives;
- FRMS processes and procedures;
- Accountabilities, responsibilities and authorities for these processes and procedures;
- Mechanisms for ongoing involvement of management, ATCOs, and all other involved personnel;
- FRMS training programme, training requirements and attendance records;
- Scheduled and actual rosters, duty periods and rest periods with deviations and reasons for deviations noted;
- FRMS outputs including findings from collected data, recommendations, and actions taken; and
- FSAG terms of reference.

Annex F Prevention and mitigation measures for ATCO fatigue

F.1 Approach

One of the objectives of the study was to review and analyse the effectiveness of existing and new approaches to prevent and mitigate ATCO fatigue (beyond the adjustment of the rosters design) for delivering the acceptable levels of safety. The main research question of this task of the study was: "*What are the most effective and practical means for mitigating ATCO fatigue according to experts?".* A panel of experts with various backgrounds was invited to answer the research question by means of a three-round online Delphi study. This methodology uses group-based judgment to reach consensus within a certain topic where the scientific evidence is still scarce, in this case regarding the effectiveness of fatigue mitigation measures for ATCOs.

The starting point was the identification of measures that can potentially be used to prevent high fatigue in ATCOs or to effectively manage experienced fatigue. The list of these measures was created using five different sources:

1. Interviews and surveys with ATSPs.
2. Literature review.
3. Roster specific interviews with ATSPs.
4. Existing knowledge within consortium
5. Additional literature review regarding knowledge in other domains (a 'review of reviews').

Based on this methodology, a total of 31 fatigue mitigation and/or prevention measures was presented to the panel of experts. The Delphi study consisted of three online questionnaire rounds in which experts were invited to indicate to what extent they found the measures effective for, and applicable to, European ATCOs. Participants were also asked to motivate their answers and it was possible for them to add measures themselves as well. Consensus was reached when at least 80% of the participants had a similar opinion. In the third and final round of this study, participants were asked to rank all measures that had reached positive consensus on effectiveness and applicability.

To make sure that a representative group of experts was involved, several actions were taken. Since the focus of this study is on fatigue in European ATCOs, the selected experts consisted of European fatigue and sleep researchers working in the field of aviation and/or shift work. To extend the field of expertise, other sleep and fatigue researchers were also invited, such as researchers from other regions of the world and researchers from other domains, such as transport and medicine. Next to scientific experts, operational experts were included as well. Suggestions for these experts came from different members of the multidisciplinary consortium. In addition, operational experts that were already involved in the study were also approached. The operational experts consisted of managers, supervisors, and ATCOs who were union representatives. Furthermore, five operational experts from the EASA advisory bodies (selected by EASA) were invited to participate. Finally, a number of training experts were added to assess the effectiveness and practical applicability of interventions from a training perspective. The training experts, a mixture of Human Factors (with ATSP experience) and ATCO training experts, were approached through contacts within the European Association for Aviation Psychology (EAAP). For this study, the aim was to have at least 10 participants who would complete the three rounds of the Delphi procedure. Since the intensity of the method may cause participants to drop out of the study, a list of 43 to be contacted experts was created. Of these experts, 14 were sleep and fatigue scientists, 11 operational experts, and 20 were human factors experts with a vast amount of experience within the ATC domain. The personalized and dedicated approach to engage the experts proved to be effective: in each round, the number of experts that responded differed, but the overall participation rate remained high (≥70%).

For further information on the approach and results of the analysis refer to the study deliverable D-2.E.

F.2 Effective and applicable measures

The resulting list of effective and applicable measures, using the 80% cut-off for reaching consensus, includes six items. However, closer inspection of the round 3 data showed that if a somewhat less rigid cut-off would have been applied, a larger list of effective and applicable measures would have been found. If the cut-off percentage would have been lowered to 75%, the total number of effective and applicable measures would have been ten, and if it would have been lowered to 73% the list would have consisted of 13 items. In addition to the list of measures with the 80% cut-off, the table below displays the measures that would have been added if the consensus was set to 75% or 73% respectively.

Table F-1: List of applicable measures ranked from most effective (top) to least effective, using the different consensus cut-offs.

Rank	ID	Measure	Cut-off %
1	V	Implement or create an FRMS to structure mitigating measures	80%
2	T	Provide bedrooms near OPS room to allow ATCOs to sleep (before, during or after shift)	80%
3	U	Provide quiet rest facilities near OPS room	80%
4	X	Introduce an educational programme about strategies to enhance adaptation to shift work (e.g. by means of light exposure, physical activity, nutrition)	80%
5	R	Promote pre-duty napping (e.g. before a night shift)	80%
6	Q	Promote napping during breaks	80%
7	AC	Post operational analysis to find out what aspects caused high workload (e.g. through perceived complexity), and subsequently apply an optimal distribution between high and low workload periods, leading to an equal distribution of workload amongst ATCOs, and a reduction in stress and fatigue	75%
8	AE	Strategic use of caffeine during shifts, in combination with other measures like naps, exercise, etc	75%
9	K	Train supervisors to detect fatigue in ATCOs	75%
10	AD	Optimization (e.g. by supervisors) of traffic demand patterns and complexity to reduce workload and subsequent mental fatigue and stress	75%
11	Z	Introduce stress reduction training (e.g. mindfulness, biofeedback training, or CBT-I) to improve sleep	73%
12	W	Have an (external) coach or psychologist available to support employees experiencing fatigue and sleep problems	73%
13	F	Allow ATCOs to do (minor) physical activity during work to maintain vigilance	73%

F.3 Discussion on implementation

In this section the measures included in Table F-1 and the possibilities to implement them are discussed in more detail.

Measures ranked 1 to 6

If we focus on the six measures deemed most effective and applicable for ATCOs to reduce and/or mitigate fatigue it can be seen that two of these measures reflect the working conditions (bedrooms and quiet rest facilities) in ATSPs. Furthermore, three measures reflect the increase of workers' capacity to cope with irregular working hours, through education and raising awareness about effective strategies, and the application of pre-duty napping or napping during breaks. In addition, while napping was already one of the few mitigating measures found effective in the ATCO specific literature review (see Chapter 3), it can be argued that both bedrooms and/or appropriate facilities are conditional for ATCOs to be able to rest and/or sleep effectively.

The measure that was indicated to be most effective by the experts, was the more general and high level measure 'implementation or creation of a Fatigue Risk Management System to structure mitigating measures'. This indicates that the experts expect that mitigation measures alone might not be enough to manage fatigue in ATCOs, but that a more systematic approach is needed to link the measures to be applied to a thorough (predictive, pro-active, and/or reactive) identification of the fatigue threats. As such, the measures described should be considered part of an FRMS, and having this as an overarching requirement would therefore be an enabler in itself. Through the arguments provided by the experts however, it became apparent that the success of an FRMS and its accompanying elements is dependent on the quality of the implementation, the time and effort spent, and an effective monitoring of ATCO fatigue levels. The different fatigue mitigation measures elements could be highlighted within the existing EASA guidance material to support the effective implementation of an FRMS.

The combination of measures reflect both organisational and personal aspects, and therefore pose a shared responsibility in order for ATCOs to be -and stay- 'fit for duty'. Increasing the feeling of personal responsibility towards being fit for duty, has been shown to be necessary for the successful implementation of any means to prevent or mitigate ATCO fatigue. This feeling of personal responsibility can be encouraged by training/education concerning the effects of fitness/unfitness on ATC performance with special reference to human factor aspects, healthy lifestyle, fatigue, and mental health. In addition, allowing the target population to co-create these interventions and tailoring the medium (e.g. choose between an eLearning and classroom training) and content to the individual user, has been shown to increase the effectiveness (e.g. van Drongelen et al., 2014). For instance, whereas a young ATCO would benefit from general knowledge regarding sleep hygiene[34] in order to be able to sleep well despite irregular working hours, a more experienced ATCO might profit more from specific information about how to cope with night shifts, since these shifts tend to become more difficult with increasing age.

An important consideration regarding training and/or education is that besides ATCOs, planners, supervisors, and managers should be trained as well. Thus ensuring they are also aware of the causes and risks of fatigue and that they can recognize (and therefore prevent) excessive fatigue in themselves and others. Furthermore, one could think of the parallel implementation of Peer Support Programmes (PSPs) within the ATSPs and providing information about PSPs for ATCOs. Finally, if the above is embedded in a just culture, this will automatically lead to ATCOs within an organization to be able to report unfit for duty with impunity. This unfit reporting itself could lead to additional research on the shift schedules and thus be followed up by corrective measures, which will contribute to an even better organisational culture.

[34] Healthy habits, behaviours and environmental factors that can be adjusted to improve sleep quality and quantity.

Measures ranked 7 to 13

Looking at the seven measures that could have been considered as effective and applicable if the cut-off applied was lower, four more measures address healthy behaviour and coping strategies of ATCOs themselves (coaching of employees with sleep problems, stress reduction training to improve sleep, caffeine, physical activity during work). Whereas the promotion of strategic usage of caffeine and physical activity during work could be part of the content of the training/education programs as described above, the other two interventions would require a more thorough approach. Having a coach or psychologist available to support employees would for instance require hiring an external specialist that should be available for individual ATCOs who have fatigue and/or sleep problems at predetermined timeslots (either physical or online). The introduction of a stress reduction training to improve sleep would require an external specialist as well, while it should also be decided upfront which type of training would suit the target population best. Whereas for instance mindfulness training is relatively accessible and can applied in a classroom based setting, CBT-I is an individual training targeting the frustrations that accompany symptoms of insomnia. As for the other measures, the choice which measure to implement, and how, should be based on the needs and wishes of the target population, the measures already put in place, and the culture within an ATSP.

Another measure in the additional list of seven concerns the training of supervisors to detect fatigue in ATCOs. Although this sounds like a relatively easy measure to implement, multiple experts expressed their doubts regarding its applicability (the supervisor is not always around, and the implementation would require an appropriate safety culture) and effectivity, since the detection method should be proven to be effective first.

Interestingly, the final two additional measures in the list reflect workload management (post operational workload analysis and subsequent redistribution, and pro-active optimization of traffic demand and complexity). It has been widely documented that high workload can lead to an increase in fatigue (e.g. Nealley & Gawron, 2015; Li et al., 2022), which suggests that lowering workload could help to decrease ATCO fatigue during shifts as well. The concerns of the experts were therefore not on the effectivity, but more on the applicability of these measures. They would for instance require the availability of specific data and tools, which could differ between ATSPs (e.g. depending on their size). The implementation could also be limited due to operational constraints, and airlines may not always support the effect of these kind of interventions (e.g. on the available slots). If however these barriers do not (or only limited) exist in a certain ATSP, these interventions are thought to be effective measures to prevent fatigue.

Monitoring effectiveness of interventions

It should be acknowledged that for most measures additional scientific studies are needed to prove their effectiveness. The literature reviewed in Chapter 3 showed there is little evidence on effective mitigations, besides for napping. Additional scientific studies are recommended because the evidence for their effectivity in ATSPs and ATCOs is still scarce and the potential benefit of specific operational and organizational conditions may be context dependent. Yet, the measures that were listed as a result of the Delphi study can be regarded as a set of fatigue mitigation measures for ATSPs to choose from, taking into account their own culture, working conditions, ATCO population, and the measures already in place.

Annex G Potential impact of technology on ATCO workload and fatigue

G.1 The relationship between workload, fatigue, and technology

ATCO workload and fatigue are related, as ATCO workload is one of the predictors of ATCO fatigue (see Figure G-1), as has been shown by studies in various settings (e.g. Marcil & Vincent, 2000; Triyanti et al, 2020; Bongo & Seva, 2022, Chen et al., 2019). Both periods of high workload and those of low workload can cause ATCO fatigue, just as the presence of repetitive tasks (Nealley & Gawron, 2015), with the latter often being called drowsiness. Importantly, when workload is affected due to the implementation of ATCO supporting technologies, the level of fatigue may be affected accordingly. When automation takes over tasks from the ATCO, the ATCO may experience lower workload. However, when too little workload is experienced by the ATCO over a period of time, both drowsiness and inattentiveness may take effect, effectively increasing ATCO fatigue. This may be especially the case in periods of a circadian low, i.e. during night shifts. However, ATCOs may also experience heightened workload in relation to the implementation of new technologies, for instance if the technology support leads to an unfavourable task distribution, overloads certain cognitive processes, or is not trusted by the ATCO, for example due to the potential of system errors or nuisance alerts.

Several ATCO supporting technologies may reduce workload or positively affect ATCO performance given a certain workload by taking away routine and repetitive tasks, increasing an ATCO's situational awareness, look-ahead horizon and sense of control, relieving data acquisition, supporting decision-making, lessening execution tasks and backing up human intervention (Wang et al., 2021). On the other hand, ATCO supporting technologies may also increase workload, or negatively impact ATCO performance given a certain workload, by adding new tasks or decreasing the sense of control. This may lead to stress, skill degradation, and may increase drowsiness in case of monotony or a feeling of being out-of-the-loop. Since ATCO supporting technologies have a varying impact on workload, it may be concluded that the same applies to the impact on ATCO fatigue. There might be an indirect impact of a specific supporting technology to ATCO fatigue, but that might be indistinguishable from other main causes of ATCO fatigue (e.g. rostering, workload management etc.).

It is possible to assess a change in workload due to a specific ATCO supporting technology in specific situations through human-in-the-loop experiments for example, which are performed in many (SESAR) technology development projects.

In the study, the following assessment methods were applied in in the assessment of the impact of ATCO supporting technologies on ATCO workload and fatigue.

1. direct approach;
2. consultation of ATCOs as a qualitative all-over assessment;
3. expert opinion and analysis;
4. human-in-the-loop experiments;
5. a model-based approach;

While all approaches have potential benefits, they are also limited in their suitability to assess the more generic effect of technology on ATCO workload and fatigue. The extent to which each of these technology reduces workload and possibly fatigue is wholly dependent on the specific ATCO position in a specific operational environment, considering the specific conditions of the ATSP. It was found that for various reasons it is not feasible to unanimously quantify the impact of technology on workload and fatigue in general terms and it is not feasible to quantify the added value of the listed technologies in terms of a percentage-change of workload or fatigue that may be expected. See D-3.A for a further discussion.

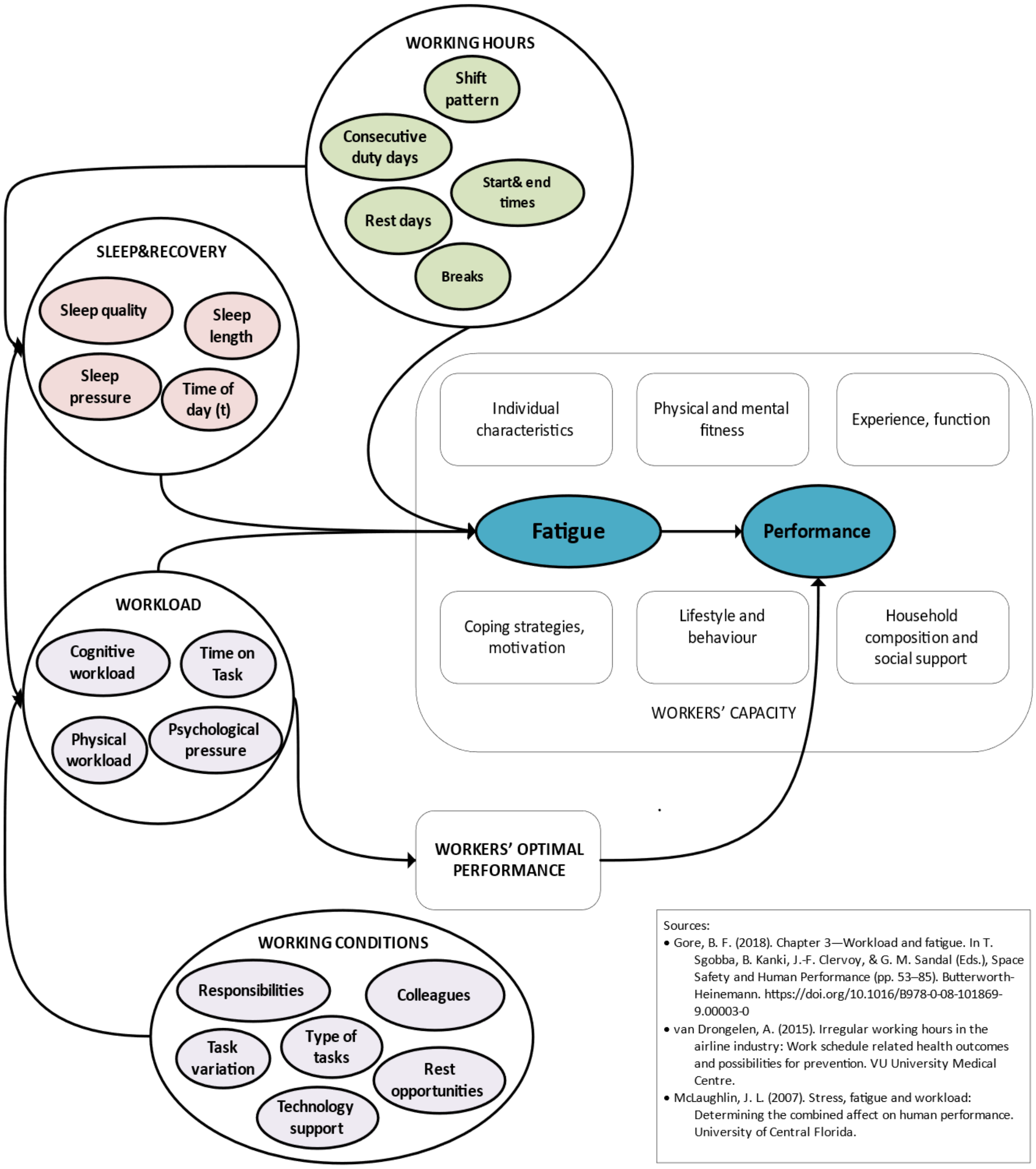

Figure G-1: Conceptual model of factors influencing fatigue and human performance

G.2 Guidelines to cover ATCO fatigue in technology development

This section summarises guidance for conducting a human-centric approach in the context of ATCO fatigue and (future) technology development to consider systematically and appropriately ATCO workload and fatigue in the design, development and implementation of (future) ATCO supporting technologies. As part of the described human-centric approach, good practices are outlined for conducting a Human Performance Assessment (HPA), including a Human-In-The-Loop (HITL) experiment, for addressing fatigue threats of future technology. A good practice for addressing the hazard of drowsiness in the context of ATCO fatigue and (future) technology is included as well.

G.2.1 A step-by-step human-centric approach to alleviate ATCO fatigue

The section describes a human-centric approach to address fatigue risks and associated fatigue factors in the context of (future) technology development and implementation. The following section provides guidance on how these steps can be performed in practice. The described human-centric approach can be adopted by ATSPs in the following case. Suppose that as part of the reactive FRMS process an ATSP has identified that the amount of workload is a significant contributing factor to fatigue. The ATSP has already considered several fatigue prevention or mitigations measures (e.g., provide bedrooms near OPS room to allow ATCOs to sleep, provide quiet rest facilities, etc.), optimising ATCO staffing per duty, or by redistributing tasks. On top of that, or besides, the ATSP could seek a solution to alleviate ATCO workload/fatigue by means of implementing ATCO supporting technologies. The following step-by-step approach is then recommended.

Step 1: Assess workload for the specific ATCO position

Identify per ATCO position, and possibly per individual, in which domain (i.e., in terms of operational or cognitive tasks) the workload is most significant. This can be done by evaluating traffic complexity information, by analysing fatigue threats (based on fatigue reports) and by asking ATCOs about their experience and opinions through interviews, surveys or focus groups.

Step 2: Consider to perform an additional Human Performance Assessment

If step 1 does not lead to a clear set of operational tasks that constitute the fatigue threat, a HPA could be initiated to specify the domain in which the workload is most significant in terms of cognitive processes (i.e. information acquisition, information analysis, decision and action selection and action implementation) or resources (e.g. manual, vocal, visual, spatial). Moreover, a HPA within ATC aims to evaluate the capabilities, limitations and effectiveness of ATCOs and groups of ATCOs in performing their operational tasks and may encompass a wide range of techniques. Further details on *how* to conduct a HPA can be found below.

Step 3: Identify and select potential technologies

Once it is known from step 1 and 2 in which domain the workload for a specific ATCO position is most significant, technologies within that domain can be considered. In particular, ATSPs are advised to consider technologies that a) reduce the specific tasks by automation and b) assist controllers to look ahead further in time, and c) distribute tasks more evenly over time and between controllers. The technologies can be selected on the basis of in-house ATCO operational expertise[35], human factor knowledge about the specific ATCO position, literature (e.g., about SESAR research) and experience from ATSPs which have introduced the technology already in operational practice.

Step 4: Conduct human-in-the-loop experiments

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[35] ACTOs within an ATSP might be tasked as dedicated technology evaluators, to a limited extent comparable to test pilots for flight operations. Such technology evaluators might also assist in setting up experiments as presented in the next bullet.

A human-centric approach is essential in the final selection and implementation of any technology. An important step is the evaluation of the impact of the selected technology on workload and fatigue for the specific ATCO position, operational conditions of the ATSP. The HITL experiments are an important activity in this selection process. The common practice is to execute such human-in-the-loop experiments under ceteris paribus conditions, meaning the same traffic is handled by the same controller under the same conditions with the only exception that in one set of simulation runs the (new) technology is applied and in another set of runs the (new) technology is not applied. Measurement of workload and fatigue in these HITL experiments can be performed using subjective workload and fatigue assessment methods. This will be addressed in the next section. The results of the HITL experiment should be used to validate and update the HPA.

Step 5: Analyse and balance automation versus the role of the ATCO
Before introducing technologies that reduce specific task load by automation, the following should be considered as a precaution. Two prevalent contributing factors to fatigue are monotonous situations and low work load situations (or combined, especially during the night). While the selected technologies could reduce the workload during traffic peaks or complex traffic situations, they may increase monotony and introduce low workload or underload during off-peaks (unintended), which might lead to drowsiness. It is therefore recommended to analyse the balance between the automation and the ATCO. Perhaps, the automation could be designed in such a way that it functions only in the circumstances in which it is needed to reduce workload. However, such considerations are highly technology-dependent so no general conclusions can be drawn other than that it requires careful consideration of the design team.

Step 6: Monitoring the effectiveness
After a technology has been introduced the recommend method to evaluate the expected impact and effectiveness of a technology is to regularly monitoring the as part of the FRMS. A mature FRMS has closed Deming cycles (plan-do-check-act, or comparable notions). The best practice would then be to simply follow such iterative approach; that is: to define measurable objectives for implementing the technology beforehand (such as: *a reduction of 10% of fatigue reports during peak hours for that ATCO position* or: *at least 70% of the ATCOs answers the question on the reduction of workload by this technology in a positive way*), to specify in advance how the implementation is verified and validated, to verify and validate and then to act on the basis of the validation information. As indicated, this process should be standardised within the FRMS of the ATSP, with sufficient freedom for the ATSP to define such process.

G.2.2 Approach to human performance assessment addressing ATCO fatigue

This section delves into the topic of how ATCO workload and fatigue can be integrated in a human performance assessment, as part of the step 2 and possibly step 4 of the human-centric approach described before. This section will cover added value, objectives, content and methodology before providing details on how workload and fatigue can be measured in an operational setting, for example as part of a HITL experiment.

Added value
By applying a HPA covering ATCO fatigue (and not only ATCO workload), future ATCO supporting technology could be designed, developed and implemented so that qualified ATCOs can safely perform tasks in various operational conditions. This means that appropriate consideration can be given to hazards that may lead to fatigue and drowsiness, and that conditions conducive of fatigue and drowsiness can be addressed in the design and development phase.

Objective
The objectives of a Human Performance Assessment addressing fatigue threats of future ATCO supporting technology should be the following:

- Identify, assess and mitigate the potential hazards of the new technology that may negatively impact workload and/or fatigue of ATCOs.
- Identify, assess and implement if necessary potential interventions for preventing or mitigating ATCO fatigue as a results of ATCO supporting technology in conditions conducive of ATCO fatigue and drowsiness.
- Identify, assess and mitigate the potential effects of fatigued ATCOs working with technology with the aim to support the ATCO in the safe performance of operational tasks when fatigued/drowsy, and/or to alleviate the negative impact of fatigue and drowsiness through ATCO supporting technology (e.g. by an adaptive Human Machine Interface (HMI)).

Content of the HPA

First, it is important to fully understand the tasks that are involved in ATC operations, so a more detailed measure of gaining insight into these matters is by conducting a task analysis. Automation exists that can complete a task analysis on future technologies as well, which can be used by developers of new automation for example (Medina et al, 2010). The next step involves establishing specific performance metrics that can assess how well ATCOs can execute the tasks that are identified in the task analysis. Common examples of such metrics depend on the task at hand, but prediction in ATC may for instance be measured with by response time (RT) or success rate of detecting a situation (Xu & Rantanen, 2003). Other metrics may include assessing the accuracy of statements made by controllers and their adherence to procedures, or determine an ATCOs workload or situational awareness. In certain cases, it may be beneficial to test an ATCOs performance in a simulated environment, as some situations do not occur frequently or may endanger actual flights. Hence, simulators are a useful tool when evaluating ATCOs under different conditions such as difficult weather circumstances, maximum traffic volume and emergencies, or even a combination of these, for example. When assessing performance in the field is possible, observational methods are a useful tool to gain insights into how well an ATCO is able to execute tasks. An observer may be a well-trained and experienced controller, but may also be automation that looks at specific parameters that have shown to be important indicators of a controller's performance on certain tasks. It is also possible to do an analysis afterwards, by reviewing ATC communications or radar track data.

Importantly, a HPA is not a one-time assessment, but it rather reflects an ongoing process to identify which areas can be improved, especially with the introduction of new technologies or processes in the operational environment. For instance, such an assessment was done to assess ATCO workload in Multiple Remote Tower Operations (MRTO; Kearney et al., 2020). Such an analysis highlights the areas in which new concepts are still lacking in comparison with existing operations and where more research or changes to the implementation of a new concept are needed.

Perform the assessment with a view on ATCO fatigue

During the human performance assessment, the analyst is recommended to:

- Identify, assess and address the impact of hazards related to the technology on ATCO workload and fatigue for the local implementation, practices, procedures. This means that the HPA should be tailored to the ATSP, specific ATCO position, and local operational conditions.
- Consider potential fatigue threats. Consider at a minimum hazards of drowsiness, sleepiness and lapse of attention due to combinations of low task load, high monotony in task execution, limited sense of control and working during the night.
- Identify and consider various operational conditions conducive of ATCO fatigue, such as working at night, low traffic, monotonous working conditions, high workload and fatigue building up over time. In addition, identify circumstances and factors that may lead to drowsiness, such as working during night-time and early morning duties, lack of staff redundancy to provide breaks, low traffic demand, monotonous situations and repetitive tasks
- Assess the following aspects in relation to technology:

- – Interchanging functions between systems and several humans;
  - – Managing unexpected events in a highly automated environment;
  - – Decision-making when lots of information might be relevant;
  - – Passively receiving information;
  - – Trust in integrated information and system-derived advices;
  - – Variable task load;
  - – Individual management of workload.
- Assess the impact of ATCO fatigue on cognitive tasks performance in relation to the specific (future) technology. It is know that fatigue impacts cognitive tasks, and therefore the analysts should take into account how the task performance may be affected or supported in case of the specific technology under analysis.

Perform the HITL experiments with a view on ATCO fatigue

It is recommended to adopt the following two practices when measuring ATCO workload and fatigue in an operational setting, for example as part of a HITL experiment. Firstly, include a diverse range of representative operational scenarios, including conditions that are conducive of fatigue, drowsiness, sleepiness and lapse of attention. Further, include in scenarios working at night-time and conducting experiments with fatigued controllers. Secondly, consider the usage of a combination of subjective and objective measurements techniques for workload and fatigue. Often, objective and subjective measures complement one another, and objective measures could be used to assess the validity of subjective measurements. Subjective fatigue and workload ratings, using validated measurement techniques, and usage of objective measurements techniques are addressed in Annex E .

Addressing drowsiness

Addressing the hazard of drowsiness in relation to technology as part of a HPA can be done using the following two steps:

<u>Step 1: Identify and assess drowsiness for the specific ATCO position</u>

Identify per ATCO position, and possibly per individual, under which circumstances and due to which factors drowsiness appears in current operations and/or can be expected in case of the future technology. For example, consider working at night and early morning duties, staffing levels and lack of redundancy in staffing to provide rest breaks, low traffic demand, monotonous traffic situations and/or repetitive tasks.

<u>Step 2: Identify and assess potential intervention strategies</u>

Bring a team of ATCOs and Human Factors experts together to identify potential measures to counter the hazard of drowsiness. One of the potential measures to reduce the likelihood of drowsiness by reduction of automation under the circumstances in which drowsiness occurs, while still applying the automation in other circumstances. Aspects to consider include:

- Shifting information processing from machine to human;
- Providing more information (e.g., further in time ahead);
- Shifting action execution from machine to human.

Another intervention to consider is to identify periods when controllers can reduce the tactical traffic handling to a minimum, such that they could execute other tasks or could relax in order to avoid fatigue later on in the shift. Technology could, in those conditions, monitor the traffic situation and provide a warning in case of situations that require human intervention. Although such a way of operating within the ATC domain is largely unexplored, it may become feasible with evolving ATCO supporting technologies, especially in the area of flight conformance monitoring. This area would require further analysis to assess potential hazards.

Comparing two technologies regarding their impact

Finally, there is a possibility that one would want to compare two different (ATCO supporting) technologies when it comes to their impact on ATCO workload and fatigue. In that case, it is possible to design and conduct a HITL experiment with the aim to collect data and measure the difference in impact on ATCO workload, cognitive tasks and fatigue between two technologies having different automation levels. The experiments would for example be conducted in two scenarios against one reference baseline. The two scenarios represent the two different technologies having different automation levels. Using subjective and objective measurements, researchers could then analyse the results of the simulations with the one technology against the baseline and the other technology against the same baseline, using appropriate statistical methods.

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