Australian Government
Civil Aviation Safety Authority

Fatigue management resources guide - Publications and applications

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Revision history

Amendments/revisions of this guide are recorded below in order of most recent first.

Version No.	Date	Parts/Sections	Details
1.0	March 2024	All	First issue

Introduction

This document provides a list of relevant scientific publications, along with an outline of useful fatigue management tools and resources (including the 2021 biomathematical modelling - supplemental update).

In addition to their experience with fatigue, these resources and tools may assist an operator in their fatigue hazard identification and management processes.

1 Relevant publications

All publications listed below have been openly sourced via the internet using Google, Google Scholar, PubMed or Research Gate search engines.

1.1 Air crew fatigue

Caldwell, J. A. , Mallis, M. M. , Caldwell, J. L. , Paul, M. A. , Miller, J. C. , & Neri, D. F. (2009). Fatigue countermeasures in aviation. *Aviation Space and Environmental Medicine, 80 (1),* 29-59.

Caldwell, J. A. & Caldwell, J. L. (2016). *Fatigue in aviation: a guide to staying awake at the stick* (2nd Ed.). New York, NY, Routledge.

Dinges, D. , Graeber, C. , Rosekind, M. , Samel, A. , & Wegmann, H. (1996). *Principles and guidelines for duty and rest scheduling in commercial aviation*. NASA Technical Memorandum 110404, May 1996, 8.

Hartzler, B. M. (2014). Fatigue on the flight deck: the consequences of sleep loss and the benefits of napping. *Accident Analysis & Prevention, 62,* 309-318.

Honn, K. A. , Satterfield, B. C. , McCauley, P. , Caldwell, J. L. , & Van Dongen, H. P. (2016). Fatiguing effect of multiple take-offs and landings in regional airline operations. *Accident Analysis & Prevention, 86,* 199-208.

Lopez, N. , Previc, F. H. , Fischer, J. , Heitz, R. P. , & Engle, R. W. (2012). Effects of sleep deprivation on cognitive performance by United States Air Force pilots. *Journal of Applied Research in Memory and Cognition, 1,* 27-33.

Marqueze, E. C. , Nicola, A. C. B. , Diniz, D. H. M. D. , & Fischer, F. M. (2017). Working hours associated with unintentional sleep at work among airline pilots. *Revista de Saúde Pública*, *51,* 1-10.

Powell, D. , Spencer, M. B. , Holland, D. , Broadbent, E. , & Petrie, K. J. (2007). Pilot fatigue in short-haul operations: Effects of number of sectors, duty length, and time of day. *Aviation, Space, and Environmental Medicine, 78,* 698-701.

Powell, D. , Spencer, M. B. , Holland, D. , Broadbent, E. , & Petrie, K. J. (2007). Pilot fatigue in short-haul operations: Effects of number of sectors, duty length, and time of day. *Aviation, Space, and Environmental Medicine, 78*, 698-701.

Simons, M. & Spencer, M. (2007). Extension of flying duty period by in-flight relief. *TNO-DV* 2007 C362.

Vervodja, M. , Elmenhorst, E. M. , Pennig, S. , Plath, G. , Maass, H. , Basner, M. , et al. (2014). Significance of time awake for predicting pilots' fatigue on short-haul flights: implications for flight and duty time regulations. *Journal of Sleep Research, 23,* 564-567.

1.2 Fatigue prevention, prediction and countermeasures

Caldwell, J. A. , Caldwell, J. L. , Thompson, L. A. , & Lieberman, H. R. (2018). Fatigue and its management in the workplace. *Neuroscience & Biobehavioral Reviews, 96,* 272-289.

Caldwell, J. A. , Mallis, M. M. , Caldwell, J. L. , Paul, M. A. , Miller, J. C. , & Neri, D. F. (2009). Fatigue countermeasures in aviation. *Aviation, Space, and Environmental Medicine, 80,* 29-59.

[CASA (2014). Biomathematical Fatigue Models. Civil Aviation Safety Authority.]

Dawson, D. & McCulloch, K. (2005). Managing fatigue: it's about sleep. *Sleep Medicine Reviews, 9*, 365-380.

Dawson, D. & Reid, K. (1997). Fatigue, alcohol and performance impairment*. Nature, 388,* 235.

Dawson, D. , Noy, Y. I. , Härmä, M. , Åkerstedt, T. , & Belenky, G. (2011). Modelling fatigue and the use of fatigue models in work setting. *Accident Analysis & Prevention, 43,* 549-564.

Folkard, S. & Tucker, P. (2003). Shift work, safety and productivity. *Occupational Medicine, 53,* 95-101.

Wesensten, N. J. , Belenky, G. , Thorne, D. R. , Kautz, M. A. , & Balkin, T. J. (2004). Modafinil vs. caffeine: effects on fatigue during sleep deprivation*. Aviation, Space, and Environmental Medicine, 75*, 520-525.

2 Alertness consideration applications

There are several applications and/or online tools that may be used as a starting point in the assessment of a pilot's fatigue/alertness level. CASA has reviewed the applications listed below and considers them suitable for the purpose of alertness consideration.

Omission of an application from the list does not mean that CASA would not consider the application suitable. An operator should assess the suitability of an application based on relevant operational circumstances. Should a developer wish to have their application considered for suitability by CASA, they should contact CASA.

While operators may encourage the use of these applications to assess a pilot’s level of fatigue, the applications are not the exclusive source of fatigue assessment. If a pilot’s self-assessment outcome is that they are too fatigued to commence or continue a flight duty period, or undertake an extension, the pilot should report the circumstances and take appropriate actions. Increased fatigue awareness with the use of applications or tools that result in pilot decisions to not commence or to discontinue flight duty periods need to be supported by operators, if, and when they occur and documented within their fatigue/safety management systems.

2.1 FatigueSafe*

The FatigueSafe app is designed to be a quick personal self-check tool consisting of six questions related to sleep and fatigue. The questions concern recent sleep quality and quantity, the presence of physical and mental signs of fatigue, and importantly, if the person feels fit to engage in activities such as work, driving, etc. It is designed to complement (not replace) additional defences within a Fatigue Management System.

It takes a minute to complete a test, and the person is given a green, amber or red outcome and any instructions for further action.

FatigueSafe is available on both the iOS App Store and the Google Play Store.

*Application assessed on 22/07/2020.

2.2 Fatigue Guru*

The Fatigue Guru app uses the ISO31000 framework and the FRM approach described by Dawson and McCulloch (2005) to support scientifically and legally defensible decision making. This app uses the working time arrangement, prior sleep-wake behaviour or self-report to estimate the level of fatigue-related risk and select the controls necessary to continue working safely.

The Fatigue Guru app is available on both the iOS App Store and the Google Play Store.

*Application assessed on 22/07/2020.

2.3 PeakAlert*

PeakAlert uses an AI-powered algorithm licensed from the US Department of Defense. It tracks and predicts performance, sleep and other crucial personal factors. The app uses objective performance, sleep and other data to create a custom algorithm to support peak alertness at specified time points. PeakAlert can import data from a range of smartphone health and sleep measuring devices.

The PeakAlert app is available on both the iOS App Store and the Google Play Store.

*****Application assessed on 22/07/2020.

3 Sleep measuring wearable devices

There is extensive interest in measuring sleep for the purpose of enhancing health and safety. Consequently, a wide range of wearable devices are available for the purpose of measuring sleep. Scientific investigation of the validity of some of these devices for sleep monitoring has contributor to their uptake.

Collectively, the research supports the use of selected Apple, Fitbit and Garmin devices (to name a few) for the measurement of total sleep time and time in bed. Evidence for more advanced sleep metrics (including sleep staging) is unclear. As mentioned previously, inclusion in this discussion is not a recommendation by CASA. Similarly, omission of a product is not a reflection on the suitability of a product. It is crucial that Operators assess the suitability of an application for operational requirements.

Some of the key references are highlighted below:

Clevenger, K. A. , Molesky, M. J. , Vusich, J. , & Montoye, A. H. (2019). Free-living comparison of physical activity and sleep data from Fitbit Activity Trackers worn on the dominant and nondominant wrists*. Measurement in Physical Education and Exercise Science, 23 (2),* 194-204.

Gruwez, A. , Bruyneel, A. V. , & Bruyneel, M. (2019). The validity of two commercially available sleep trackers and actigraphy for assessment of sleep parameters in obstructive sleep apnea patients. *PloS One, 14 (1*), e0210569.

Lee, J. M. , Byun, W. , Keill, A. , Dinkel, D. , & Seo, Y. (2018). Comparison of wearable trackers' ability to estimate sleep. *International Journal of Environmental Research and Public Health, 15(6),* 1265.

Roomkham, S. , Hittle, M. , Cheung, J. , Lovell, D. , Mignot, E. , & Perrin, D. (2019). Sleep monitoring with the Apple Watch: comparison to a clinically validated actigraph. *F1000Research, 8*, 754.

Rowe, V. T. & Neville, M. (2019). Measuring reliability of movement with accelerometry: Fitbit® versus ActiGraph®. *American Journal of Occupational Therapy, 73(2),* 1-6.

Stevens, S. , & Siengsukon, C. (2019). Commercially-available wearable provides valid estimate of sleep stages (P3. 6-042). *Neurology, 92 (15 Supplement*).

Tedesco, S. , Sica, M. , Ancillao, A. , Timmons, S. , Barton, J. , & O'Flynn, B. (2019). Validity evaluation of the Fitbit Charge2 and the Garmin vivosmart HR+ in free-living environments in an older adult cohort. *JMIR Mhealth Uhealth, 7,* e13084.

4 Sleep-measuring smartphone applications

There is an extensive list of smartphone applications available across IOS and Android platforms that are used for personal sleep tracking. However, there is limited research investigating the validity of these applications. Collectively, the research indicates there is limited evidence supporting the use of smart phone applications for the measurement of total sleep time and time in bed. The evidence for more advanced sleep metrics (including sleep staging) using these devices is unclear.

Some of the key references are highlighted below:

Bhat, S. , Ferraris, A. , Gupta, D. , Mozafarian, M. , DeBari, V. A. , Gushway-Henry, N. , et al. (2015). Is there a clinical role for smartphone sleep apps? Comparison of sleep cycle detection by a smartphone application to polysomnography*. Journal of Clinical Sleep Medicine, 11,* 709-715.

Choi, Y. K. , Demiris, G. , Lin, S. Y. , Iribarren, S. J. , Landis, C. A. , Thompson, H. J. , et al. (2018). Smartphone applications to support sleep self-management: review and evaluation. *Journal of Clinical Sleep Medicine, 14,* 1783-1790.

Fino, E. & Mazzetti, M. (2019). Monitoring healthy and disturbed sleep through smartphone applications: a review of experimental evidence. *Sleep and Breathing, 23,* 13-24.

Fino, E. , Plazzi, G. , Filardi, M. , Marzocchi, M. , Pizza, F. , Vandi, S. , et al. (2019). (Not so) Smart sleep tracking through the phone: findings from a polysomnography study testing the reliability of four sleep applications. *Journal of Sleep Research, 29.*

Halson, S. L. (2019). Sleep monitoring in athletes: motivation, methods, miscalculations and why it matters. *Sports Medicine*, https://doi. org/10. 1007/s40279-019-01119-4.

5 Biomathematical Modelling 2021 - Supplemental Update

This supplement provides an update to the publication of Biomathematical Fatigue Models Guidance Document , published March 2014. This supplement provides a brief overview of new biomathematical models of fatigue and outlines significant changes and updates to the biomathematical models.

The biomathematical models (BMMs) detailed have been reviewed by CASA and may contribute to compliance with the enhanced fatigue management obligations, minor variations and fatigue risk management systems (FRMS). Nonetheless, like all possible tools available for fatigue risk assessment their inclusion is optional.

5.1 Consistency in terminology

For simplicity and consistency CASA has used a standard terminology across biomathematical models. That is, similar biomathematical model inputs and outputs (e. g. predicted sleep and task load) are described using consistent terms. The biomathematical model providers may use different terminology and CASA encourages organisations considering acquiring a biomathematical model to contact the providers directly for a full demonstration of the individual biomathematical model characteristics and/or unique features.

5.2 Differences between biomathematical models

While all BMMs are based on the homeostatic and circadian processes, they differ in their inclusion of additional factors that may affect fatigue and performance. Each model has different strengths and limitations, and no biomathematical model accounts for all possible contributors to fatigue. CASA requires organisations to use a range of processes (which may include the use of biomathematical models) when identifying fatigue hazards and risks. Further, when using a biomathematical model, an operator must have a sound understanding of a model’s limitations and applicability within their operational context (see IATA’s white paper on biomathematical model usage or Appendix A: Limitations for use of Biomathematical Models within CAO 48. 1).

Decisions about roster design should not be exclusively based on biomathematical model predictions. Roster design should also incorporate fatigue management scientific principles, input from aircrew, operational experience and likely conditions.

Finally, a low predicted likelihood of fatigue for a flight duty period generated by a BMM does not guarantee that the actual fatigue risk will be low. Scheduling practices should be designed as comprehensive, multidimensional systems in which a BMM can provide an optional supportive role in roster development.

5.3 Inclusion

Inclusion within this supplement is not an endorsement by CASA, nor is it a recommendation of these BMMs. Similarly, the omission of a model from this supplement does not reflect its the suitability. Operators need to assess the suitability of any BMM in relation to their operational environment and needs.

Developers who consider their model may be suitable for inclusion in future CASA supplements are invited to contact fatigue.management@casa.gov.au.

5.4 Newly included biomathematical fatigue models

Table 1: 2B Alert web

Institution	https://2b-alert-web.bhsai.org
General information	2B-Alert Web combines the validated Unified Model of Performance with a validated caffeine model to form a single, integrated modelling framework. This software tool predicts the alertness of an "average" individual as a function of sleep/wake schedule, time awake, caffeine consumption, and time of day. The corresponding fatigue predictions are displayed as three different statistics of alertness (reaction time, speed & lapses) on the psychomotor vigilance task (PVT). A smartphone app (PeakAlert) is available for both Android and iOS devices which incorporates individual PVT results into the modelling framework.
Operating Platform	Web and app-based
Data inputs*	• Sleep periods, caffeine intake, and periods of peak alertness • PVT Tests (app) • Manual entry or uploaded from an excel spreadsheet • Automatic integration of actigraphy data from third party applications (app).
Data outputs**	• Real time fatigue status expressed as PVT statistics or equivalent blood alcohol percentage (BAC %) • Fatigue alert • Optimal caffeine intake • PVT test results (app).
Limitations	• Does not currently generate fatigue estimates for trans meridian travel • Does not currently generate predicted sleep opportunities • Does not currently work with rostering programmes • Does not currently consider the influence of all components of environmental stress or workload on predicted alertness.
References	• Ramakrishnan, S. , Wesensten, N. J. , Kamimori, G. H. , Moon, J. E. Balkin, T. J. , & Reifman, J. (2016). A unified model of performance for predicting the effects of sleep and caffeine. *Sleep, 39,* 1827-1841. • Reifman, J. , Kumar, K. , Wesensten, N. J. , Tountas, N. A. , Balkin, T. J. , & Ramakrishnan, S. (2016). 2B-Alert Web: An open-access tool for predicting the effects of sleep/wake schedules and caffeine consumption on neurobehavioral performance. *Sleep, 39,* 2157-2159. • Reifman, J. , Ramakrishnan, S. , Liu, J. , Kapela, A. , Doty, T. J. , Balkin, T. J. , et al. (2018). 2B-Alert App: A mobile application for real-time individualized prediction of alertness. *Journal of Sleep Research, 23,* e12725.

* Only the major data inputs are listed based on available information and/or provider feedback. Additional data inputs may be available. Consult the software provider for additional information on the full list of available data inputs.

** Only the major data outputs are listed based on available information and/or provider feedback. Additional data outputs may be available. Consult the software provider for additional information on the full list of available data outputs.

Table 2: Aviation fatigue meter

Institution	https://pulsarinformatics.com/products/aviation
General information	Fatigue estimates provided by Fatigue Meter are based on a validated biomathematical fatigue model. This software tool predicts the alertness of an “average” individual as a function of sleep/wake schedule, sleep inertia, time awake, time of the day and time zone change. The corresponding fatigue predictions are displayed as a psychomotor vigilance task (PVT) lapse rate.
Operating Platform	Web and app based.
Data inputs*	• Sleep periods, rest periods, duty periods, departure / arrival time zones and locations • Manual entry of work and sleep schedule or integration with rostering software • Automatic integration of Fitbit actigraphy data.
Data outputs**	• Real time fatigue status expressed as a PVT lapse rate • Fatigue Alerts • Predicted sleep • Generation of fatigue estimates for duties with and without time zone changes • Custom analytical reports.
Limitations	• May under or overestimate fatigue status for trans-meridian flights • May overestimate sleep periods when using the predicted sleep function • Does not currently consider the influence of all components of environmental stress or workload on predicted alertness.
References	• McCauley, P. , Kalachev, L. V. , Mollicone, D. J. , Banks, S. , Dinges, D. F. , & Van Dongen, H. P. (2013). Dynamic circadian modulation in a biomathematical model for the effects of sleep and sleep loss on waking neurobehavioral performance. *Sleep, 36 (12),* 1987-1997.

* Only the major data inputs are listed based on available information and/or provider feedback. Additional data inputs may be available. Consult the software provider for additional information on the full list of available data inputs.

** Only the major data outputs are listed based on available information and/or provider feedback. Additional data outputs may be available. Consult the software provider for additional information on the full list of available data outputs.

5.5 Updates to models presented in the Biomathematical Fatigue Models guidance (2014)

At the date of publication, CASA could not obtain updated information on the following models: Circadian Alertness Simulator, the Fatigue Risk Index, System for Aircrew Fatigue Evaluation, and the Sleep/Wake Predictor. Accordingly, these models are not presented in this supplement update. CASA will add these models if/when updated information is available.

Table 3: Boeing Alertness Model (BAM)

Institution	www.jeppesen.com/frm
General information	The Boeing Alertness Model is built on the validated Three Process Model of Alertness. This software tool predicts the alertness of an “average” individual as a function of sleep/wake schedule, sleep inertia, time awake, time of the day, time zone change, task load and augmentation. The alertness predictions are mapped to the KSS Scale. A smartphone app (Crew Alert) is available for iOS devices.
Operating Platform	Windows, RHEL, iOS, web and app based.
Data inputs*	• Sleep periods, rest periods, duty periods, duty type, diurnal type, habitual sleep duration, departure / arrival time zones and locations • Manual entry of work and sleep schedule or integration with rostering software • Automatic integration of actigraphy data from third party applications • Custom data inputs.
Data Outputs**	• Real time predicted fatigue status mapped to the KSS Scale. • PVT, SP, and KSS test results (app) • Fatigue alerts • Recent sleep, sleep debt and time awake. • Acclimatisation status • Predicted sleep • Predicted task load • Generation of fatigue estimates for duties with and without time zone changes • Custom analytical reports.
Limitations	• May under or overestimate fatigue status for trans-meridian flights • May overestimate sleep periods when using the predicted sleep function • Does not currently consider the influence of all components of environmental stress or workload on predicted alertness.
References	• Jeppesen. (2009). Fatigue Risk Management. Available from: http://ww1. jeppesen. com/documents/aviation/pdfs/Fatigue_2009-10_Final_II. pdf . • Jeppesen. (2014). Jeppesen Fatigue Risk Management Portfolio. Available from: http://ww1. jeppesen. com/industry-solutions/aviation/commercial/fatigue-risk-management. jsp (This page provides an overview of Jeppesen FRM products and services). • Olbert, A. , Hellerstrom, D. , & Klemets, T. (2011). A comprehensive investigation of flight and duty time limitations and their ability to control crew fatigue. Available from: http://ww1. jeppesen. com/documents/aviation/commercial/GPA_white_paper. pdf

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** Only the major data outputs are listed based on available information and / or provider feedback. Additional data outputs may be available. Consult the software provider for additional information on the full list of available data outputs.

Table 4: Fatigue Assessment Tool by InterDynamics (FAID) quantum

Institution	https://www.interdynamics.com/
General information	FAID has been updated to FAID Quantum. This software tool utilises a validated biomathematical model to predict the alertness of an "average" individual as a function of rest periods, sleep/wake schedule, sleep inertia, time awake, time of the day, time zone change, and task load. The corresponding fatigue predictions are displayed as a KSS Scale or FAID Score.
Operating Platform	Desktop based or available for integration into third party software.
Data inputs*	• Sleep periods, rest periods, duty periods, duty type, departure / arrival time zones and locations • Manual entry of work and sleep schedule or integration with rostering software • Custom data inputs.
Data outputs**	• Real time fatigue status expressed as KSS or FAID score • Recent sleep, sleep debt and time awake • Predicted sleep • Predicted task load • Generation of fatigue estimates for duties with and without time zone changes • Custom analytical reports.
Limitations	• May overestimate sleep periods when using the predicted sleep function • May under or overestimate fatigue status for trans-meridian flights • Does not currently support automated integration of actigraphy data • Does not currently consider the influence of all components of environmental stress or workload on predicted alertness.
References	• Darwent, D. J, Dawson, D. & Roach, G. (2012). A model of shiftworker sleep/wake behaviour. *Accident Analysis & Prevention, 45,* supplement, pp. 6-10. • Dawson, D. & Fletcher, A. (2001). A quantitative model of work-related fatigue: background and definition. *Ergonomics, 44 (2),* 144-163. • Fletcher, A. & Dawson, D. (1997). A predictive model of work-related fatigue based on hours of work. *Journal of Occupational Health and Safety – Australia and New Zealand, 13 (5),* 471-485. • Fletcher, A. , Lamond, N. , van den Heuvel, C. , & Dawson, D. (2003). Prediction of performance during sleep deprivation and alcohol intoxication by a quantitative model of work-related fatigue. *Sleep Research Online, 5 (2),* 67-75.

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5.6 Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE)

The SAFTE model is provided through two companies, Institutes for Behaviour Resources (IBR) and Fatigue Science. These companies have different pricing structures, model outputs and software interface options. Below is an updated summary.

Table 5: Institutes for Behavioural Resources – SAFTE-FAST

Institution	https://www.saftefast.com
General information	IBR offers two versions of software: SAFTE-FAST Console and a web-based version called WebSFC. Both versions use the validated Sleep Activity Fatigue Task Effectiveness (SAFTE) model which predicts the alertness of an "average" individual as a function of rest periods, sleep/wake schedule, sleep quality, sleep inertia, time awake, time of the day, and time zone change. The fatigue predictions can be displayed as a percentage of optimal performance, PVT lapse rate, equivalent blood alcohol percentage (BAC %) and KSS or SP scales.
Operating Platform	Windows desktop and web based.
Data inputs*	• Sleep periods, sleep quality, rest periods, duty periods, duty type, departure / arrival time zones and locations • Integration with rostering software.
Data outputs**	• Real time fatigue status expressed as a percentage of optimal performance, equivalent BAC %, SP or KSS • Recent sleep, sleep debt and time awake • Fatigue alerts • Acclimatisation status • Predicted sleep • Predicted task load • Generation of fatigue estimates for duties with and without time zone changes • Custom analytical reports.
Limitations	• May under or overestimate fatigue status for trans-meridian flights • May overestimate sleep periods when using the predicted sleep function • Does not currently consider the influence of all components of environmental stress or workload on predicted alertness • Does not currently support automated integration of actigraphy data.
References	• Gertler, J. , Hursh. S. , Fanzone, J. , & Raslear, T. (2012). Validation of FAST model sleep estimates with actigraph measured sleep in locomotive engineers (Report No. DOT/FRA/ORD-12/15). Baltimore, MD: Federal Railroad Administration, U. S. Department of Transportation. • Hursh, S. R. , Raslear, T. G. , Kaye, A. S. , & Fanzone Jr. , J. F. (2007). Validation and calibration of a fatigue assessment tool for railroad work schedules (Report No. DOT/FRA/ORD-08/04). Baltimore, MD: Federal Railroad Administration, U. S. Department of Transportation. • Roma, P. G. , Hursh, S. R. , Mead, A. M. , & Nesthus, T. E. (2012). Flight attendant work/rest patterns, alertness, and performance assessment: Field validation of biomathematical fatigue modelling. Federal Aviation Administration Oklahoma City Ok Civil Aerospace Medical Inst.

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Table 6: Fatigue Science – Fatigue avoidance scheduling tool (FAST)

Institution	https://www.fatiguescience.com/fast-scheduling www.fatiguescience.com
General information	The Fatigue Avoidance Scheduling Tool (FAST) is a desktop and web-based software application that utilises the validated SAFTE model. The SAFTE model predicts the alertness of an "average" individual as a function of rest periods, sleep/wake schedule, sleep quality, sleep inertia, time awake, time of the day, and time zone change. The corresponding fatigue predictions are displayed as a percentage of optimal performance, PVT lapse rate or equivalent blood alcohol percentage (BAC %). A smartphone app (READI) is available for both android and iOS devices.
Operating Platform	Desktop, web and app.
Data inputs*	• Sleep periods, sleep quality, rest periods, duty periods, duty type, departure / arrival time zones and locations • Integration with rostering software • Automatic integration of actigraphy data via READI app.
Data outputs**	• Real time fatigue status expressed as a percentage of optimal performance or equivalent BAC % • Recent sleep, sleep debt and time awake • Fatigue alerts • Acclimatisation status • Predicted sleep • Generation of fatigue estimates for duties with and without time zone changes • Custom analytical reports.
Limitations	• May under or overestimate fatigue status for trans-meridian flights • May overestimate sleep periods when using the predicted sleep function • Does not currently consider the influence of all components of environmental stress or workload on predicted alertness.
References	• Gertler, J. , Hursh. S. , Fanzone, J. , & Raslear, T. (2012). Validation of FAST model sleep estimates with actigraph measured sleep in locomotive engineers (Report No. DOT/FRA/ORD-12/15). Baltimore, MD: Federal Railroad Administration, U. S. Department of Transportation. • Hursh, S. R. , Raslear, T. G. , Kaye, A. S. , & Fanzone Jr. , J. F. (2007). Validation and calibration of a fatigue assessment tool for railroad work schedules (Report No. DOT/FRA/ORD-08/04). Baltimore, MD: Federal Railroad Administration, U. S. Department of Transportation. • Roma, P. G. , Hursh, S. R. , Mead, A. M. , & Nesthus, T. E. (2012). Flight attendant work/rest patterns, alertness, and performance assessment: Field validation of biomathematical fatigue modelling. Federal Aviation Administration: Oklahoma City, OK. Civil Aerospace Medical Inst.

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6 Glossary

Term	Definition
Equivalent Blood Alcohol percentage (BAC %)	A level of predicted fatigue / performance impairment expressed in terms of the similar predicted fatigue / performance impairment that may occur at an equivalent percentage of blood alcohol. While this statistic can be useful for general fatigue education it must be acknowledged that this variable is generally based on reaction time metrics (speed and accuracy) and should not be used in the same legal or physiological context as an actual blood alcohol measurement.
Common data outputs (predictions)	• Fatigue alerts: A function that prompts the user regarding when significant fatigue risk is likely to occur. • Predicted fatigue status: A level of predicted fatigue / performance impairment typically expressed as an equivalent KSS, SP, PVT metrics or BAC %. • Predicted sleep: The sleep which is likely to be achieved by an individual based on their work, time zone and rest schedule. • Predicted task load: The likely influence of workload of an individual's fatigue based on the type of operation and work environment. • Recent sleep: The amount of sleep achieved in a 24 – 72 hour period. • Sleep debt: The difference between the sleep that is required and what was obtained. • Time awake: The time elapsed since awakening from a significant sleep period.
Karolinska Sleepiness Scale (KSS)	Is a 9-point scale that measures the subjective level of sleepiness at a selected time during the day. Scores on the KSS increase with longer periods of wakefulness and it strongly correlates with the time of the day. A value of 7 or higher on the KSS is associated with intrusions of sleep and an increased risk of impaired performance. 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 difficulty remaining awake 8 = sleepy, but some effort to keep awake 9 = very sleepy, great effort to keep awake, fighting sleep.
Psychomotor Vigilance Test (PVT test)	Is a reaction-time test measuring response times to a series of visual stimuli presented over a period of 3-10 minutes. The three statistics computed from the test are mean speed, mean reaction time and lapses. After establishing baseline levels for the statistics, an individual is assessed for variations in their performance across the target variables.
Samn and Perelli Score	The SP is a 7-point scale that subjectively measures an individual's level of

Term	Definition
(SP)	fatigue at a selected time during the day. This scale was originally developed to assess levels of fatigue and alertness in pilots before take-off. Typically, a mean value of 5 on the Samn-Perelli scale gives rise to some concern about the suitability of an FCM at that particular roster period (Samn & Perrelli, 1982). 1 = Fully alert, wide awake 2 = Very lively, responsive, but not at peak 3 = Okay, somewhat fresh 4 = A little tired, less than fresh 5 = Moderately tired, let down 6 = Extremely tired, very difficult to concentrate 7 = Completely exhausted, unable to function effectively.

Appendix A – Limitations for use of Biomathematical Models within CAO 48.1

The International Civil Aviation Organization (ICAO) has recommended that biomathematical modelling may be used for predictive and reactive hazard identification in duty and flight schedules as part of a comprehensive fatigue risk management system (FRMS: ICAO, 2019). The utility of BMMs is based on their ability to estimate fatigue within an operation governed by an FRMS, and do not by themselves constitute an FRMS. Importantly, BMMs should not be used to make decisions about schedule design without reference to operational experience (ICAO, 2019, 5-12).

IATA's recent White Paper (IATA, 2020) on uses and limitations of BMMs supports ICAO's perspective and highlights specific limitations, the majority of which are discussed below. The intent of this brief is to explain the contributions and limitations inherent in biomathematical modelling of fatigue in operations.

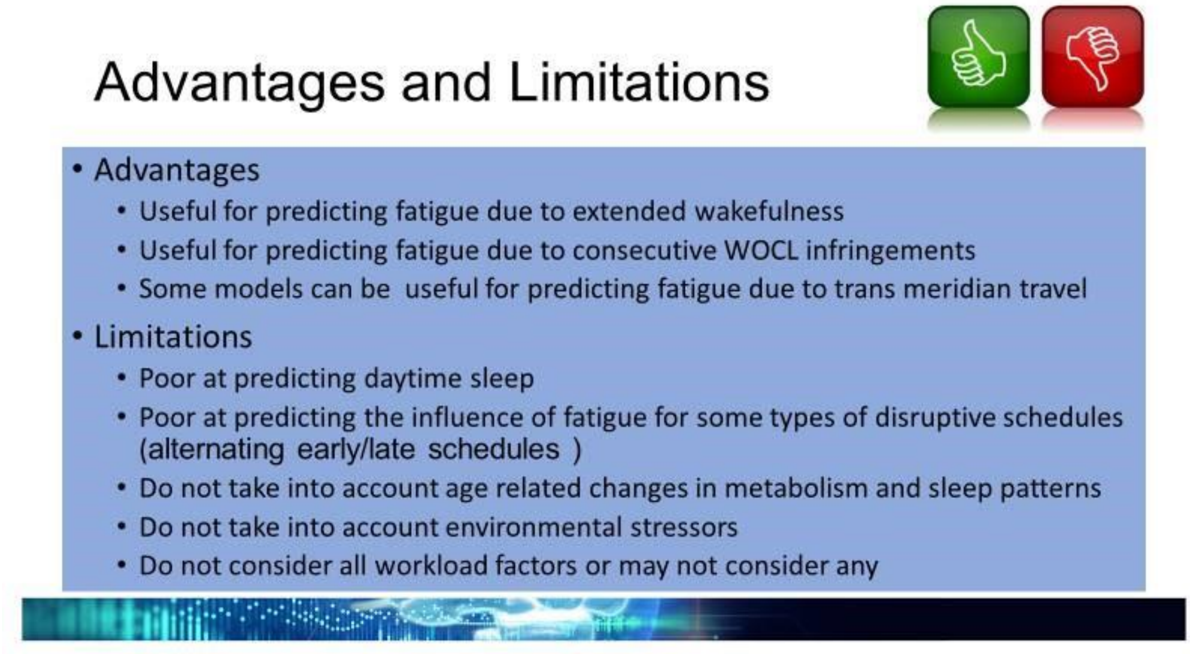
Among the numerous BMMs of fatigue that have been developed, there are common factors. Specifically, BMMs account for the relationships between sleep history, time awake and time of day (Hursh, Balkin, & Van Dongen, 2016). The models are designed to produce predictions of alertness, performance, or risk of cognitive impairment for work/rest or wake/sleep schedules being assessed. The inclusion of biomathematical model-based optimising of work schedules is an objective component among the various inputs considered for predicting operational fatigue hazards and mitigating the risks. The use of BMMs in scheduling by air operator's certificate (AOC) holders contributes to compliance with the enhanced fatigue management obligations, minor variation and FRMS requirements.

It is essential to keep in mind that these models, widely used in aviation to predict fatigue likelihood, have been developed and validated in controlled sleep-restriction or sleep-deprivation studies, or against accident probability and/or accident severity data. Most BMMs have not been robustly assessed within operational environments where a myriad of factors, including environmental stress, sleep disturbances, caffeine use, napping, and wellbeing may affect individual aircrew alertness and performance (Caldwell, Caldwell, Thompson, & Lieberman, 2019; Martinez, Quintero, & Flynn-Evans, 2015). Thus, the predictions derived from a BMM are likely to underestimate the level of fatigue being experienced within a schedule.

As numerous factors beyond those typically accounted for by BMMs contribute to an individual's operational fatigue state, BMMs cannot be validated *in situ* by an AOC holder. The AOC holder's use of a BMM is to provide guidance as to the likelihood of a schedule producing a level of fatigue given the parameters of the assumed or actual flight crew member sleep period, time awake, and the duration and time of duty.

The data that CASA requires as part of FRMS, minor variation, or enhanced fatigue management obligations should, if possible, be incorporated into the AOC holder's BMM's user specific parameters to improve the sensitivity of its prediction. This underlies CASA's recommended use of sleep durations provided by the AOC holder's data capture, rather than relying on the predicted sleep function within BMMs. The recognition of sleep as having the largest influence on a BMM's predictions of fatigue risk for a given schedule is generally held.

When presented with BMM-based justifications for flight duty periods or flight time limitations, be mindful that these rationales are incomplete. The models cannot account for the variability and unpredictability in sleep/wake behaviours; the nonlinear relationship between fatigue, task performance and safety outcomes; the actual impacts of error(s) resulting from fatigue; and the influence of fatigue risk mitigation or controls in reducing the likelihood or consequences of fatigue-related error(s) (Dawson, Darwent, & Roach, 2017). Therefore, the combination of operational experience, aircrew input, and BMM should always be clearly detailed in an operation's manual.



References

Caldwell, J. A. , Caldwell, J. L. , Thompson, L. A. , & Lieberman, H. R. (2019). Fatigue and its management in the workplace. *Neuroscience and Biobehavioral Reviews, 96,* 272-289.

Dawson, D. , Darwent, D. , & Roach, G. D. (2017). How should a bio-mathematical model be used within a fatigue risk management system to determine whether or not a working time arrangement is safe? *Accident Analysis & Prevention, 99*, 469-473.

Hursh, S. R. , Balkin, T. J. , & Van Dongen, H. P. A. (2016). Sleep and performance prediction modelling. In M. H. Kryger, T. Roth, and W. C. Dement (Eds). *Principles and practice of sleep medicine. 6th ed.* (pp. 689-696). Philadelphia, PA: Elsevier.

IATA (2020). Uses and limitations of biomathematical fatigue models – white paper. https://www. iata. org/contentassets/5f976bb3ca2446f3a40e88b18dd61fbb/uses-limitations-of-biomathematical-fatigue-models. pdf

International Civil Aviation Organization (ICAO) (2019). Doc 9966: *Manual for the oversight of Fatigue Management Approaches (2nd ed). Version 2 revised unedited*. Montreal: International Civil Aviation Organization.

Martinez, S. B. , Quintero, L. O. , & Flynn-Evans, E. (2015). Validating and Verifying Biomathematical Models of Human Fatigue. Moffett Field, CA: NASA Ames Research Center.