Fatigue and Sleep in Aviation

11TH AFRICA REGIONAL CAPSCA MEETING - NAIROBI

Dr. Mkwizu


“The best sleep happens when we listen to the body’s call for rest.”

OUTLINE

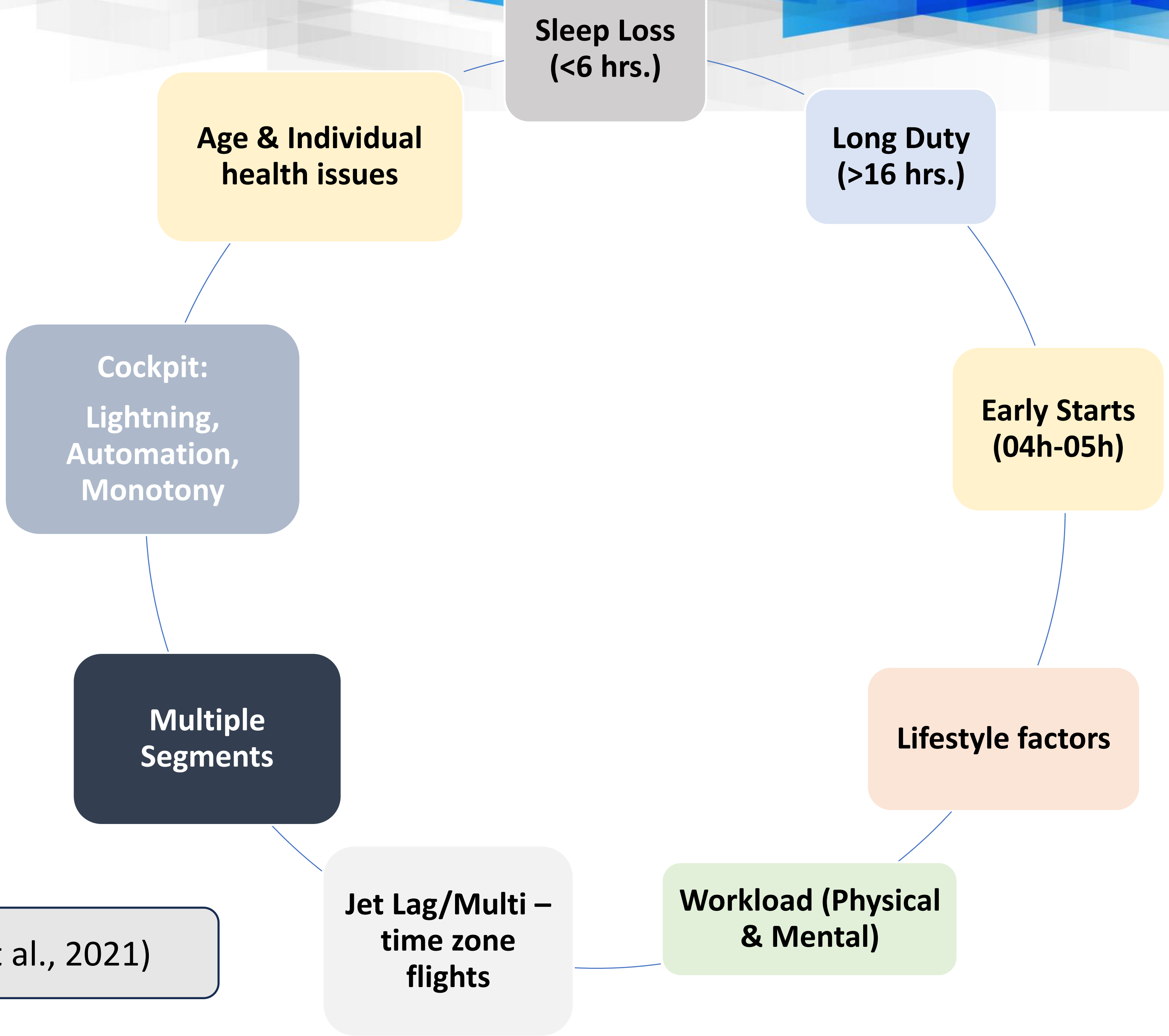
- Definitions
- Effects
- Sleep Inertia
- Bio-mathematical models
- FRMS

ICAO DEFINITION OF FATIGUE

PHYSIOLOGICAL STATE	CAUSES	EFFECTS	SAFETY IMPACT
• **Reduced mental** or **physical** performance capability	• **Sleep** loss • **Extended wakefulness** • **Circadian phase mismatch** • **Workload** (mental/physical)	• **Impaired alertness**	• **Reduced ability** to perform **safety-related duties**

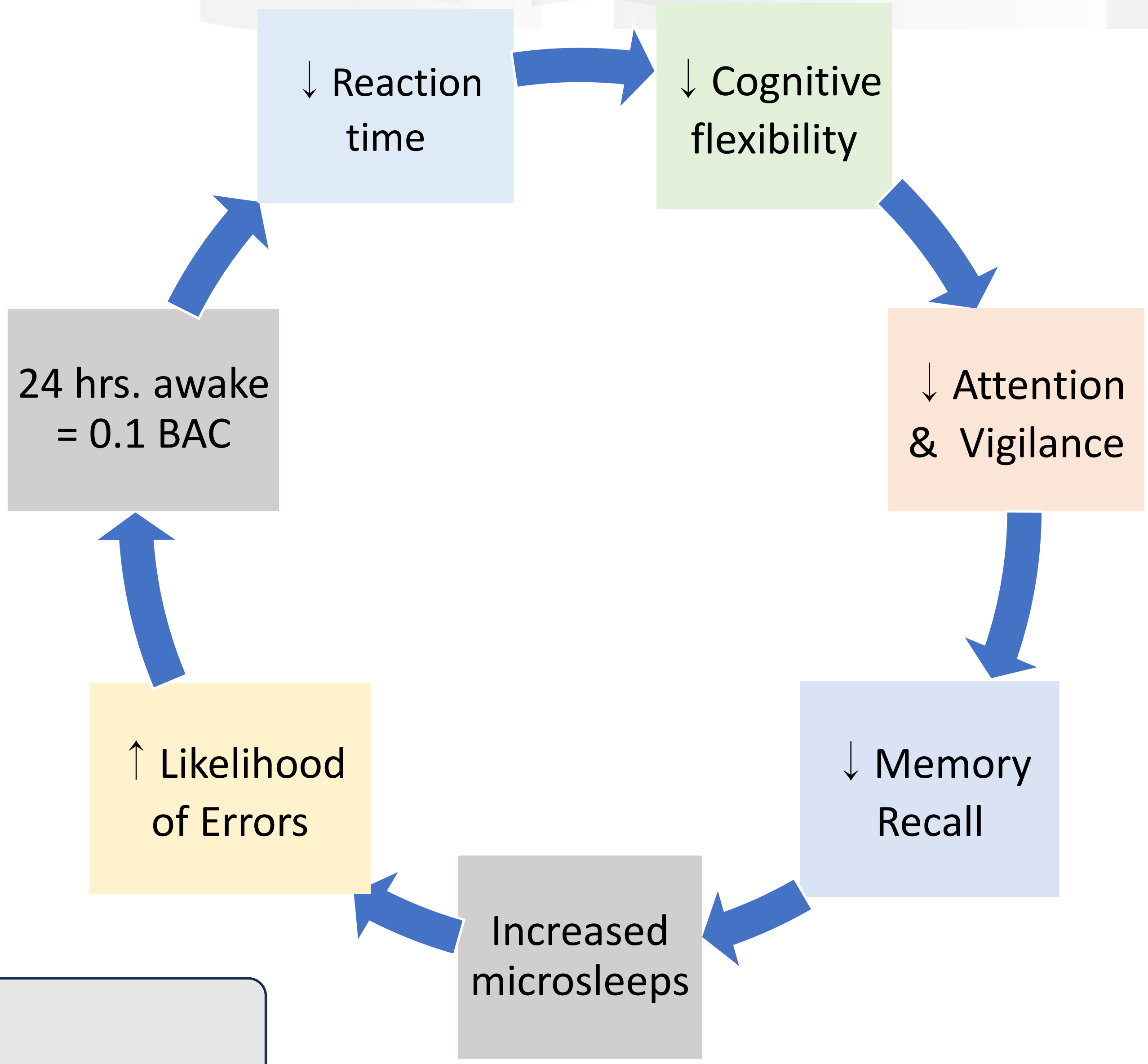
(ICAO, 2020)

CAUSES OF FATIGUE IN AVIATION



(Sharma, 2024) & (Wingelaar-Jagt et al., 2021)

IMPACT ON PILOT PERFORMANCE



Sharma, 2024

HOW WE MEASURE FATIGUE

Objective	Subjective	Prediction
• PVT • EEG/eye tracking • Wearables (PPG, HRV, ST, ACC) • ECG/EMG/GSR • Facial and gaze analysis • Actigraphy • Flight Performance deviations	• Karolinska • Samn-Perelli • Peer assessment • ASR (Aviation Safety Reports) • VAS (Visual Analogue Scale) fatigue scale	• Biomathematical models (SAFTE, FAST) • AI-based fatigue detection models • Readiness screening tools • FRMS operational data modelling

Gaze Tracking	Heart Rate (HR)	Galvanic Skin Response (GSR)	EEG
• Uses a camera or infrared sensors to examine blinking, eye closure, and gaze stability—strong markers of drowsiness.	• Measures cardiac response; fatigue reduces heart rate variability.	• Measures electrical changes on the skin when sweat glands activate—linked to mental and physical fatigue.	• Measures brain electrical activity; fatigue increases slow-wave activity and reduces alertness-related brain rhythms.

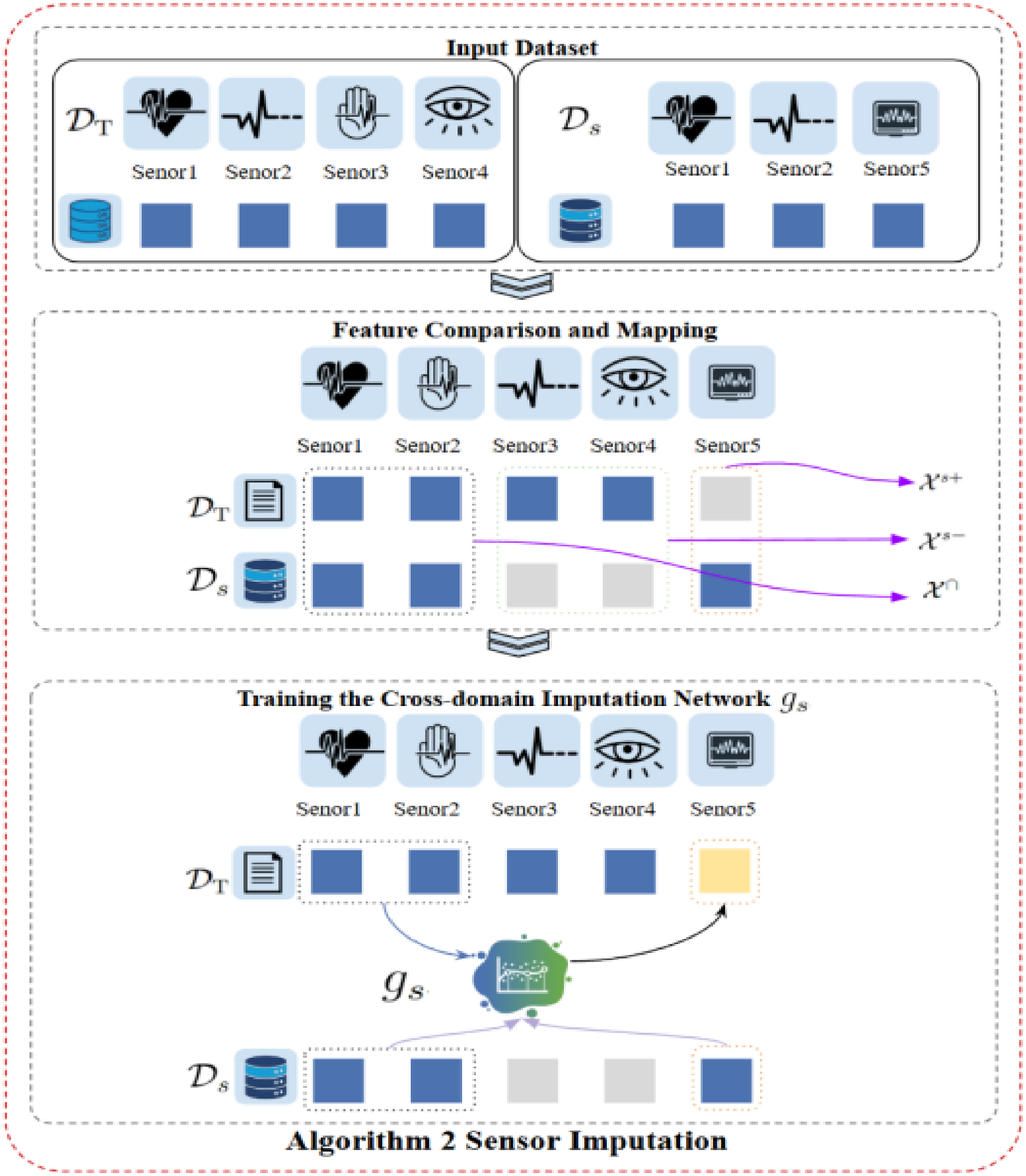
(Cui, Wu, Tang, & Li, 2025)

Photo - plethysmography (PSG)	Skin Temperature (ST)	Accelerometer (ACC)	ECG
• A light-based sensor in smartwatches that tracks blood flow, used to infer fatigue-related cardiovascular changes.	• Peripheral temperature drops slightly when fatigued.	• Detects body motion; fatigue causes small tremors and decreased posture control.	• Records the heart's electrical signals; fatigue reduces heart rate variability and alters cardiac rhythm patterns.

(Cui, Wu, Tang, & Li, 2025)

Electro myography (EMG)	Blood Pressure (BP)	Facial Features (FACE)
• Measures muscle electrical activity; fatigue reduces muscle tone and increases small tremors.	• Monitors vascular pressure; prolonged fatigue can lower blood pressure and affect autonomic regulation.	• Uses video to track yawning, eyelid drooping, and facial muscle relaxation—strong behavioral markers of drowsiness.

(Cui, Wu, Tang, & Li, 2025)



AI learns missing sensors

AI reconstructs EEC/ECG

Accurate fatigue detention with wearable only

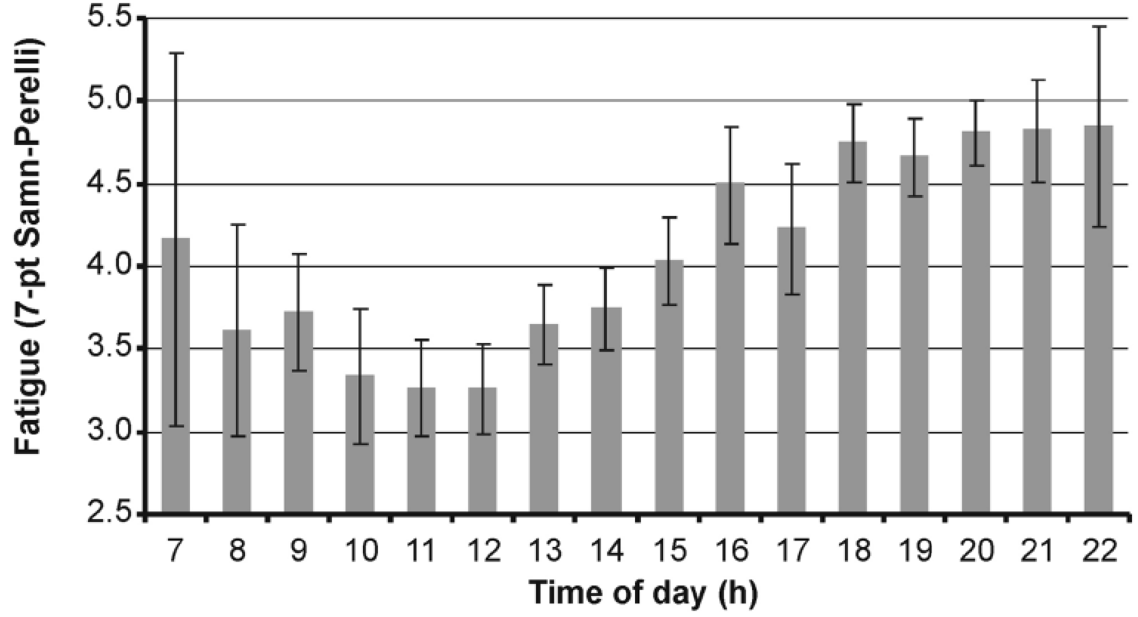
(Cui, Wu, Tang, & Li, 2025)

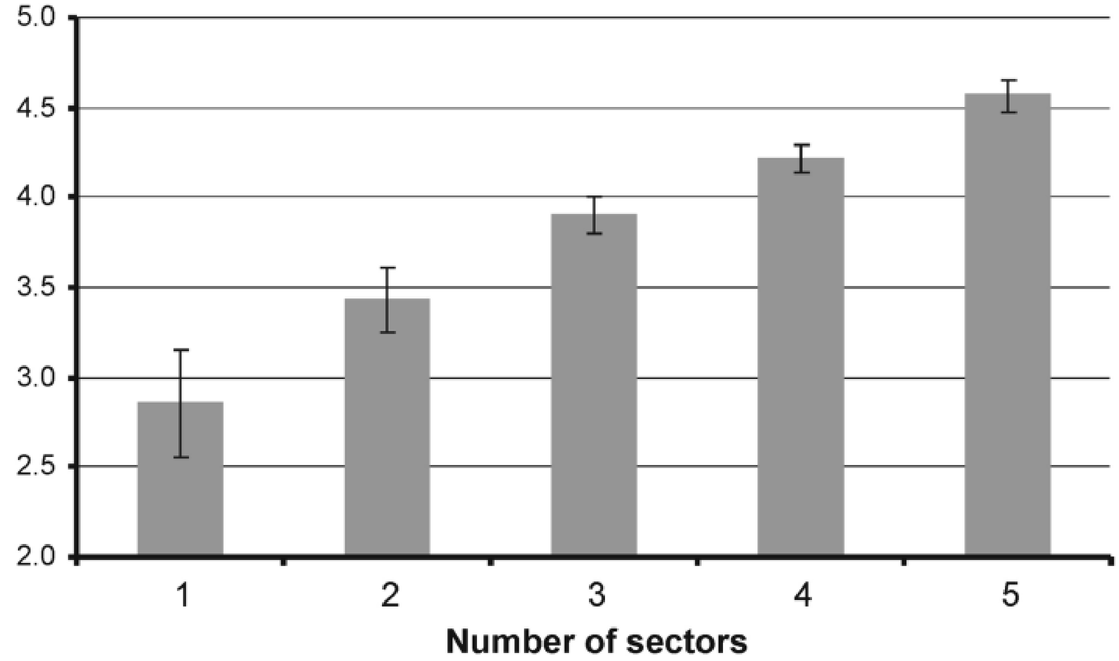
COMPARISON OF AN ACCURACY FOR CLASSIFYING FATIGUE LEVELS WITH THE STATISTICAL ANALYSIS AMONG THE CONVENTIONAL MODELS AND THE PROPOSED MODEL.

Subject	PSD–SVM [19]	DeepConvNet [20]	EEGNet [21]	MFB–CNN [22]	Proposed
S1	0.7008	0.7312	0.7618	0.7826	0.8519
S2	0.7033	0.7403	0.7774	0.7926	0.8841
S3	0.6315	0.7716	0.8003	0.8153	0.8796
S4	0.7157	0.7698	0.7997	0.8139	0.8706
S5	0.7558	0.8045	0.8506	0.8818	0.8799
S6	0.7344	0.8191	0.8529	0.8783	0.9404
S7	0.6069	0.7206	0.7601	0.7841	0.8626
S8	0.7408	0.7988	0.8126	0.8316	0.8912
S9	0.7256	0.7792	0.7991	0.8211	0.9003
S10	0.6819	0.7534	0.7879	0.8006	0.8406
Avg.	0.6997	0.7689	0.8002	0.8202	0.8801
Std.	0.0478	0.0327	0.0320	0.0353	0.0278
p–value	<0.05	<0.05	<0.05	<0.05	–

The Proposed Model was able to score at an average of 88% of all the cases of Fatigue

Lee et al., 2024

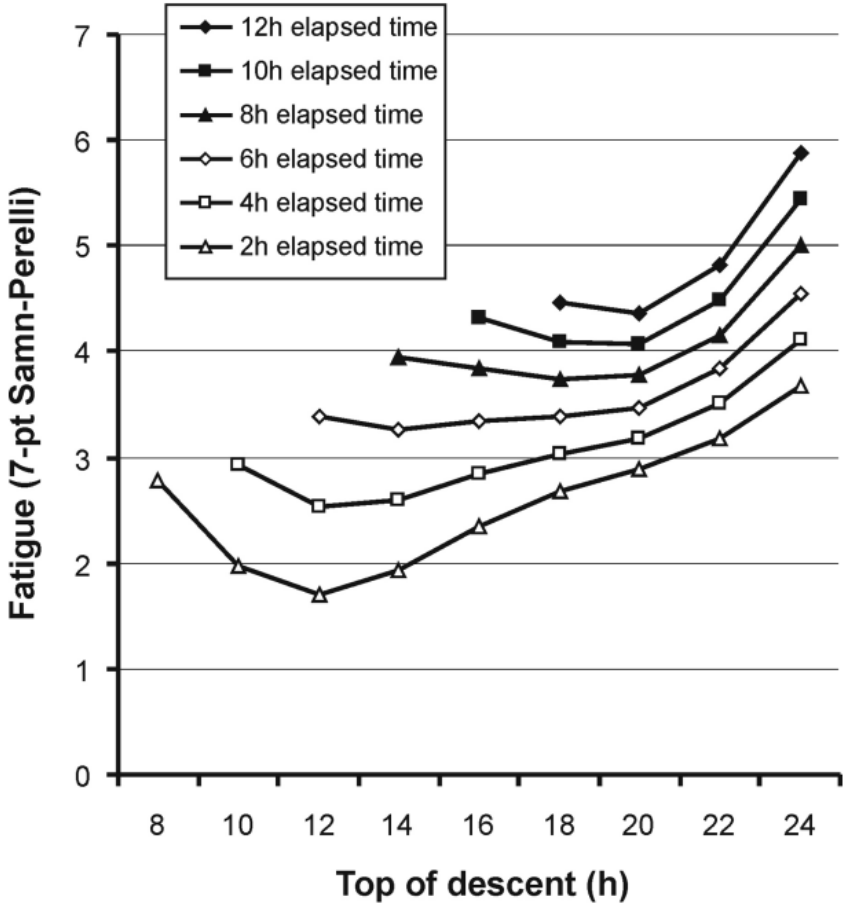


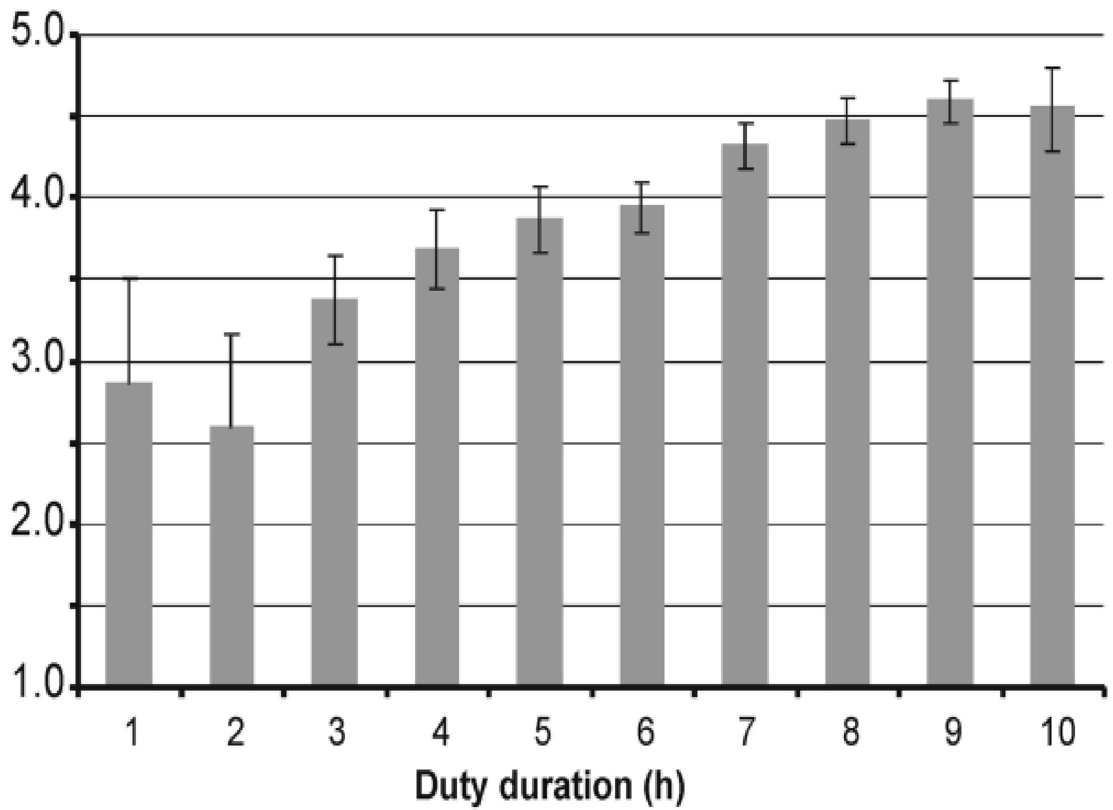


Circadian Effects and Workload Effects on Fatigue

(Powell et al., 2007)

- Fatigue is **lowest around midday** and rises steadily, reaching its **highest levels in the evening.**
- **Each additional sector adds cumulative workload**, leading to progressively **higher fatigue.**

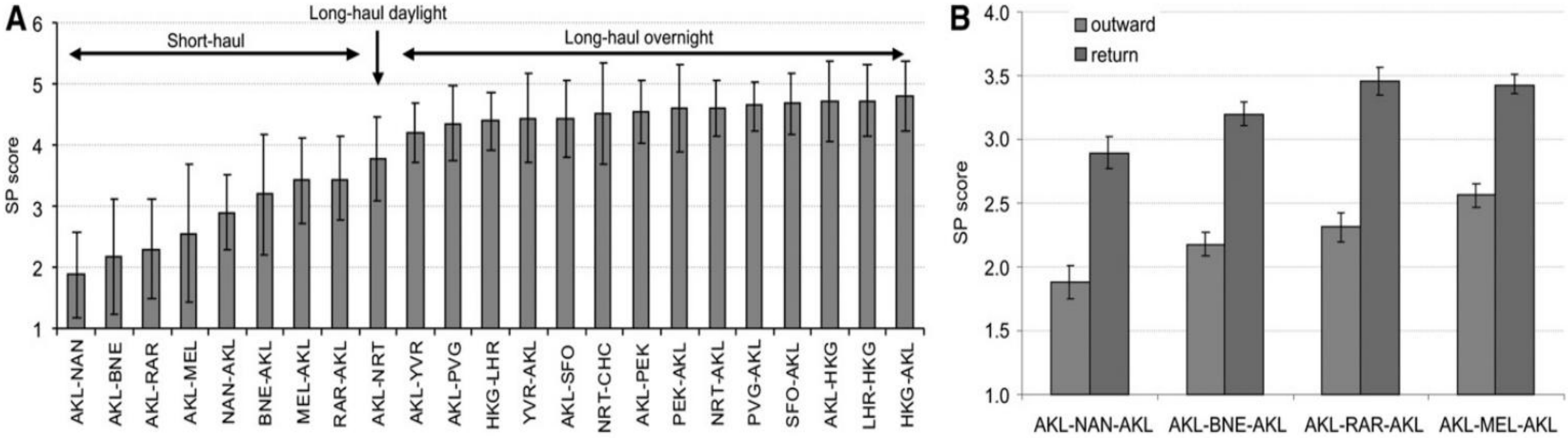




Fatigue vs Duty Length & Time of Day

(Powell et al., 2007)

- Fatigue rises steadily as duty time increases, becoming **notable after 6–8 hours.**
- Fatigue is **higher** when **top-of-descent** occurs **later in the day, especially after 18:00.**
- The highest fatigue levels occur when **long duties finish in the late evening.**

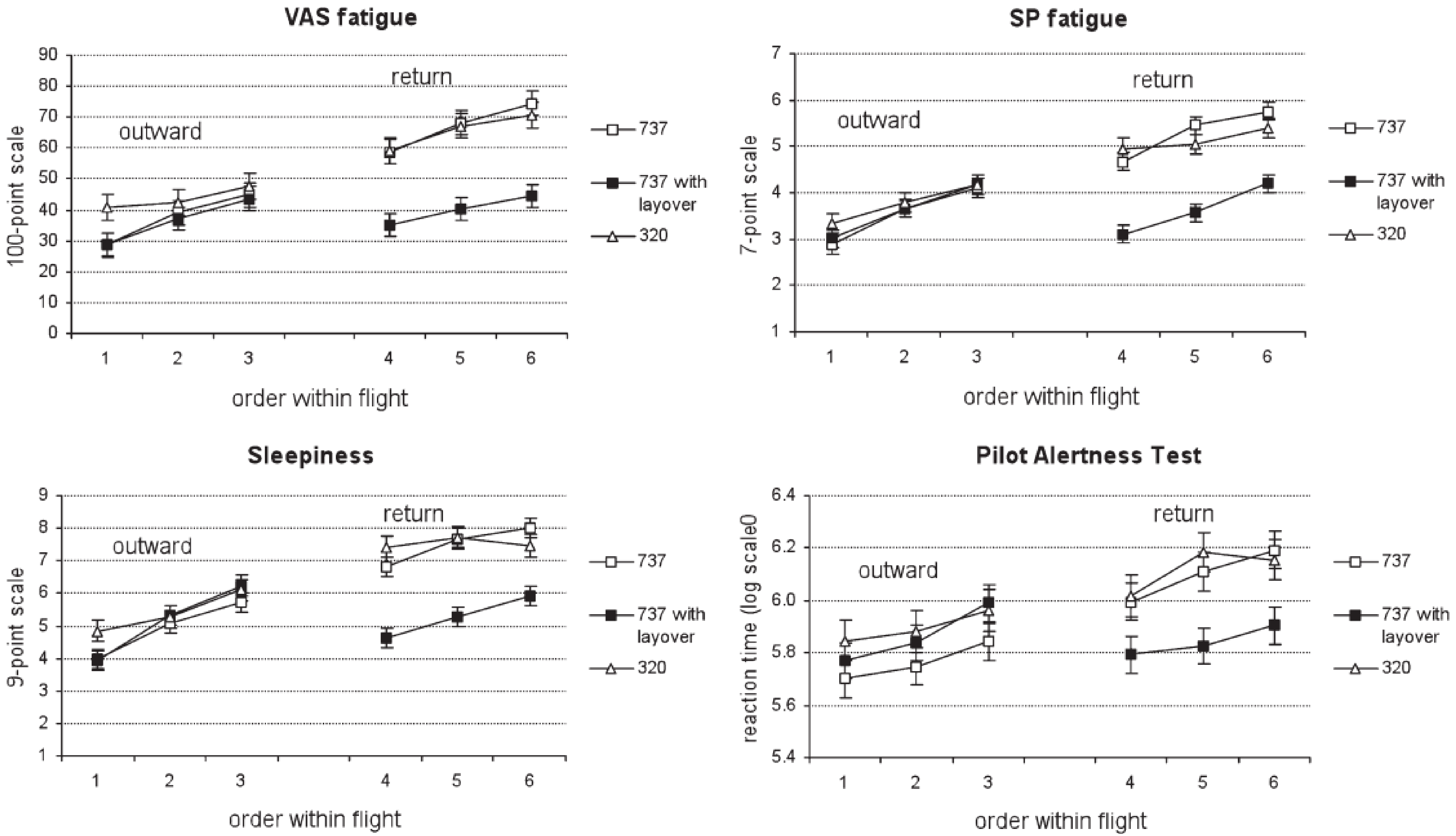


Fatigue Patterns Across Routes and Duty Sectors

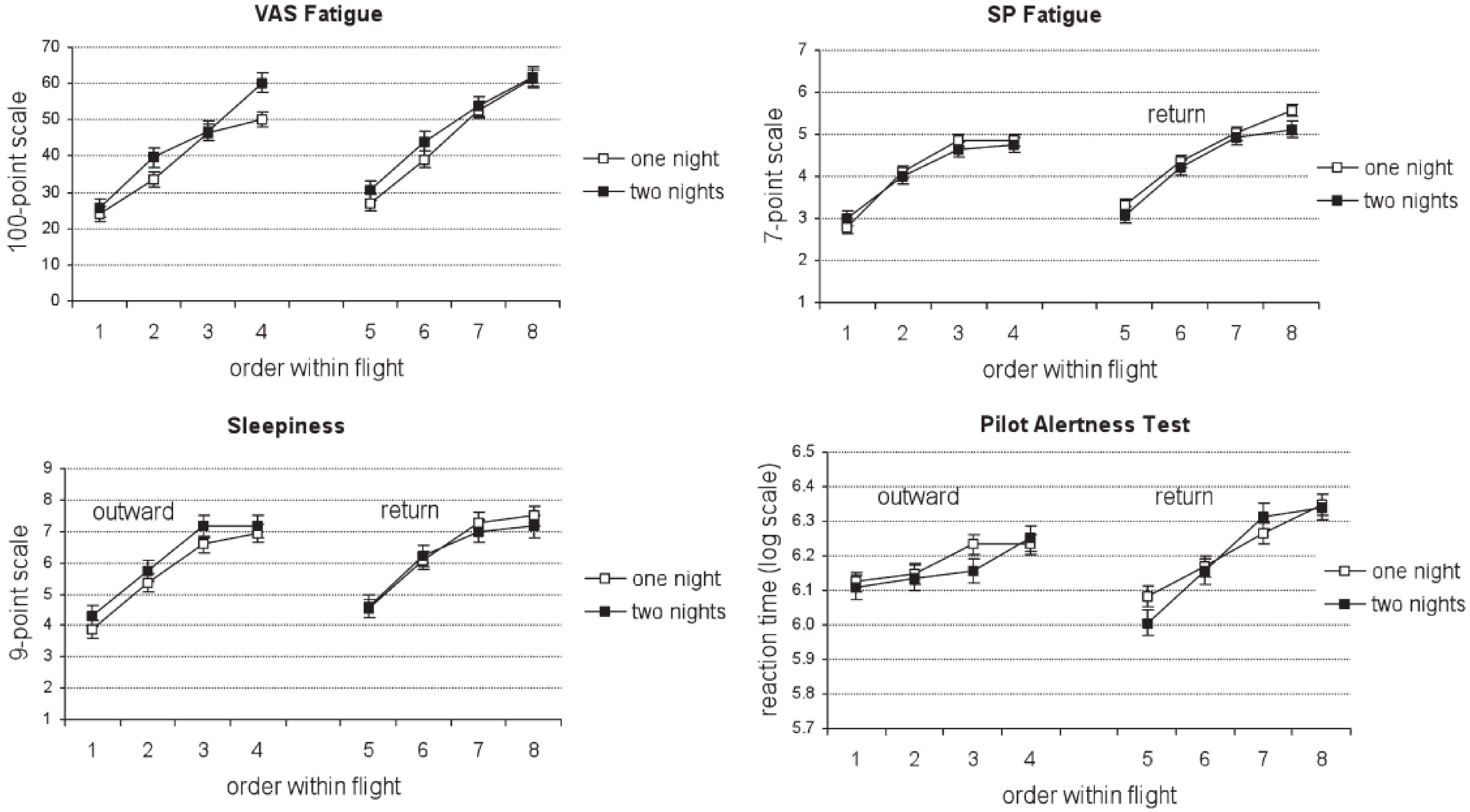
(Powell et al., 2011)

- **Short-haul daylight** flights show the **lowest fatigue.**
- **Long-haul overnight** flights produce the **highest fatigue levels.**
- **Return sectors** consistently show greater fatigue than **outbound sectors.**
- Circadian timing (night vs day) strongly influences fatigue, even when **flight duration is similar**.

Impact of Layover on Pilot Fatigue and Alertness



(Powell, Spencer & Petrie 2010)



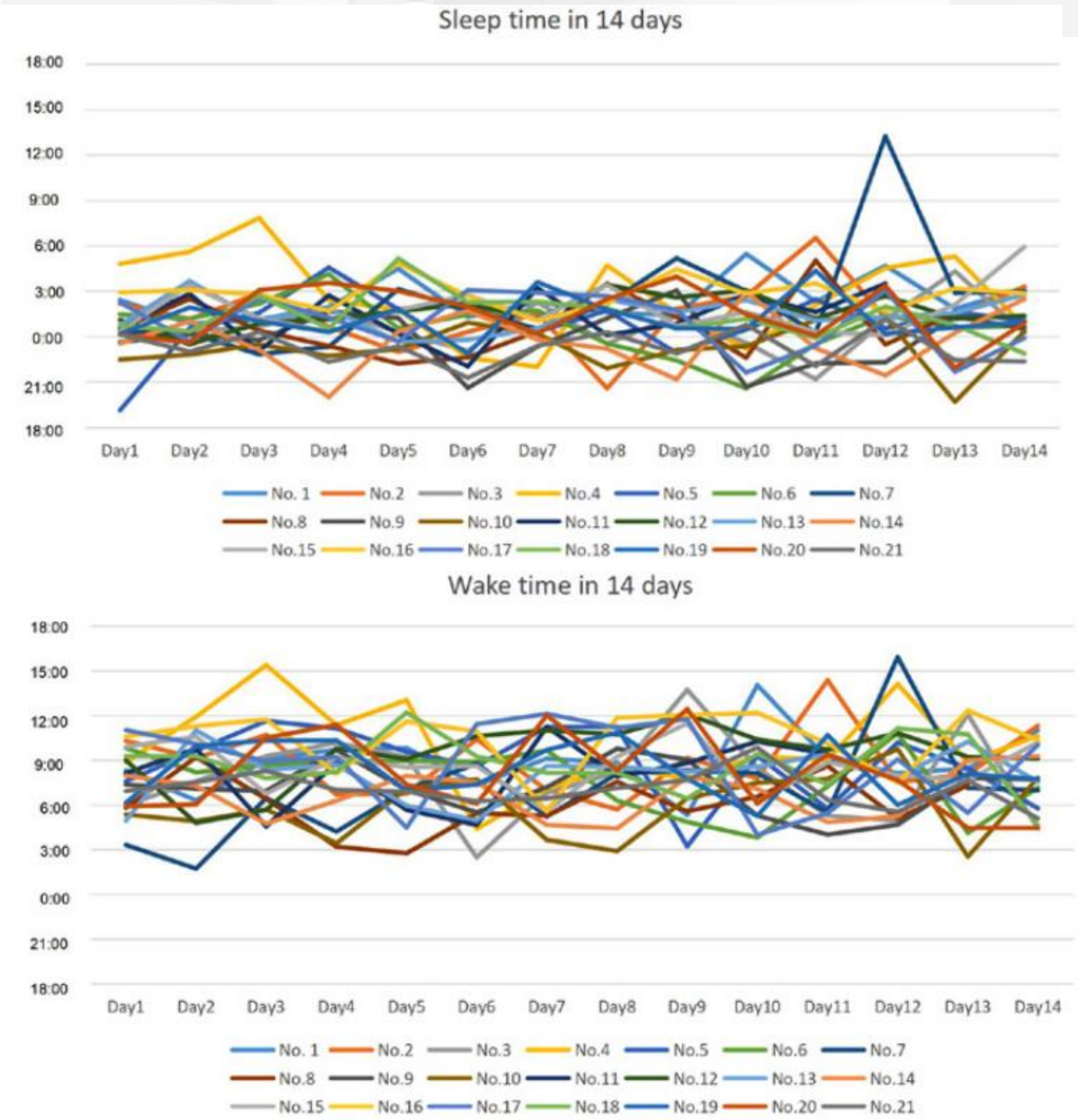
One vs Two Nights Layover: No Difference in Long-Haul Pilot Fatigue

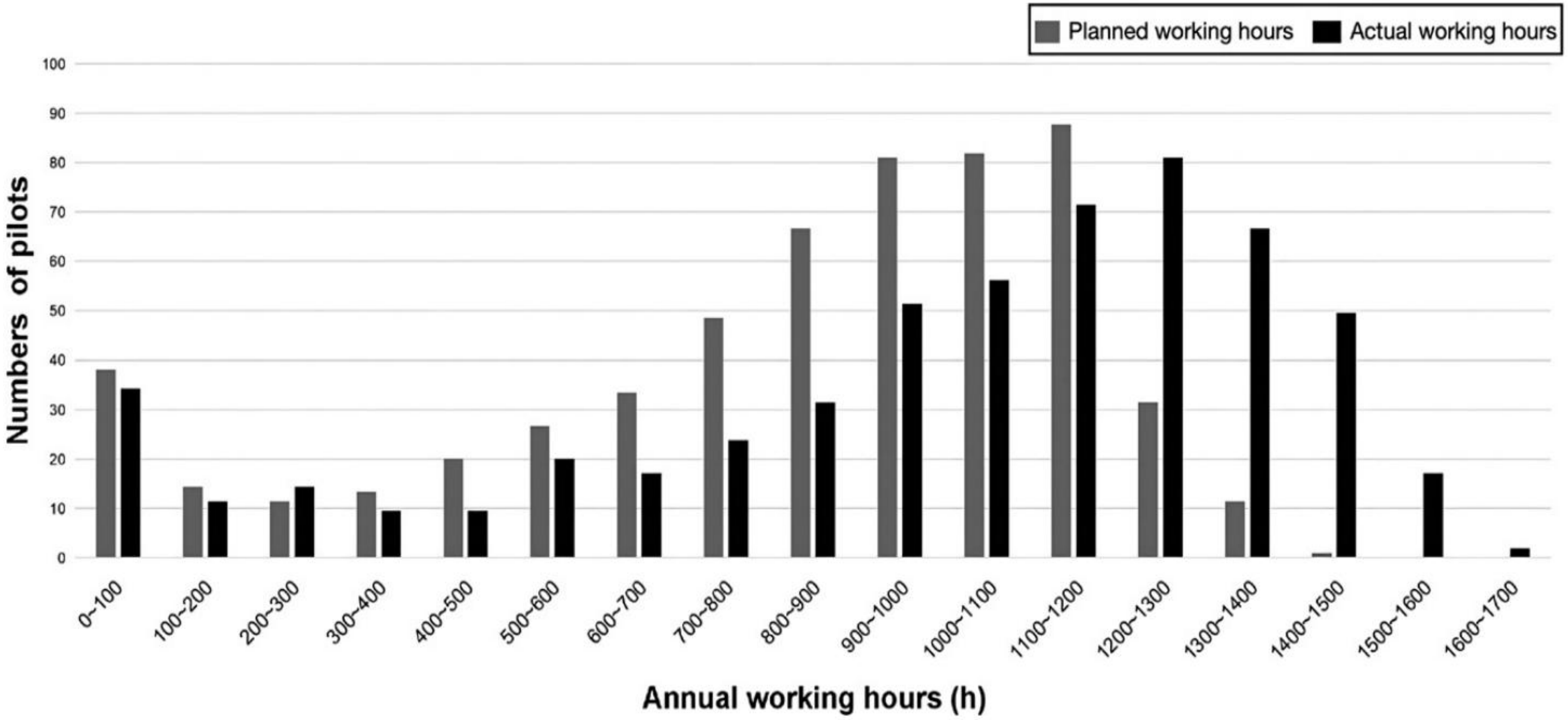
(Powell, Spencer & Petrie 2010)

EXTREME VARIABILITY IN PILOT SLEEP – WAKE PATTERNS

- **No Pilot** demonstrated a **stable sleep–wake pattern across 14 days**
- Bedtimes & wake times **vary by up to 7 hours**
- Irregular schedules **destroy circadian stability**
- Results: **chronic fatigue & impaired alertness**

(Yang et al., 2024)





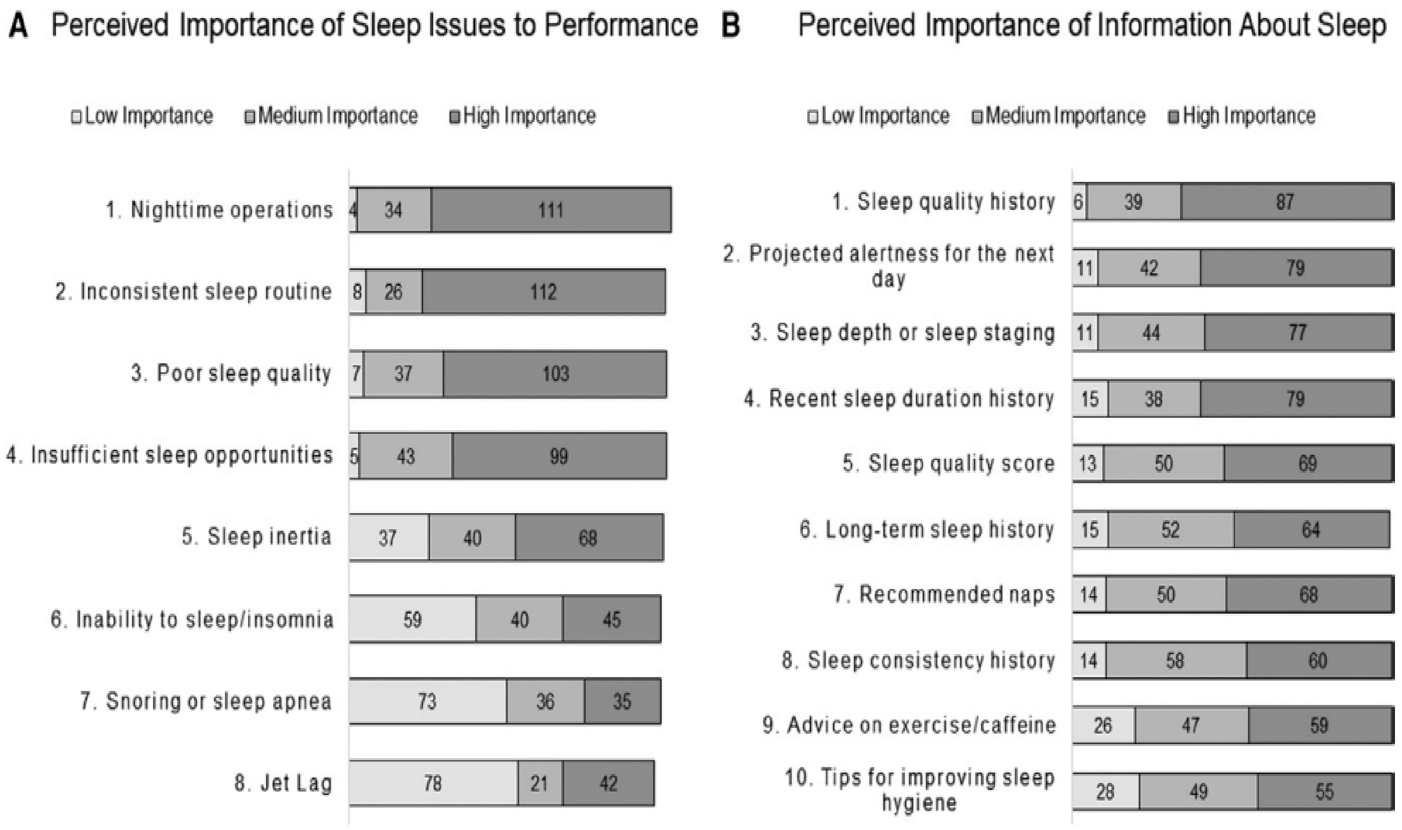
ACTUAL PILOT WORKING HOURS EXCEED PLANNED LIMITS

- **Actual hours** significantly **higher than planned across most pilots**
- Many pilots accumulate **1200–1500 hours/year**
- Actual duty hours reveal **hidden fatigue exposure**

(Yang et al., 2024)

WHAT AIRCREW SAY DRIVES FATIGUE AND THE INFORMATION THEY WANT

- Night operations = **biggest fatigue driver**
- Inconsistent routines disrupt alertness
- **Quality of sleep** matters more than hours



(Devine, Choynowski & Hursh, 2024)

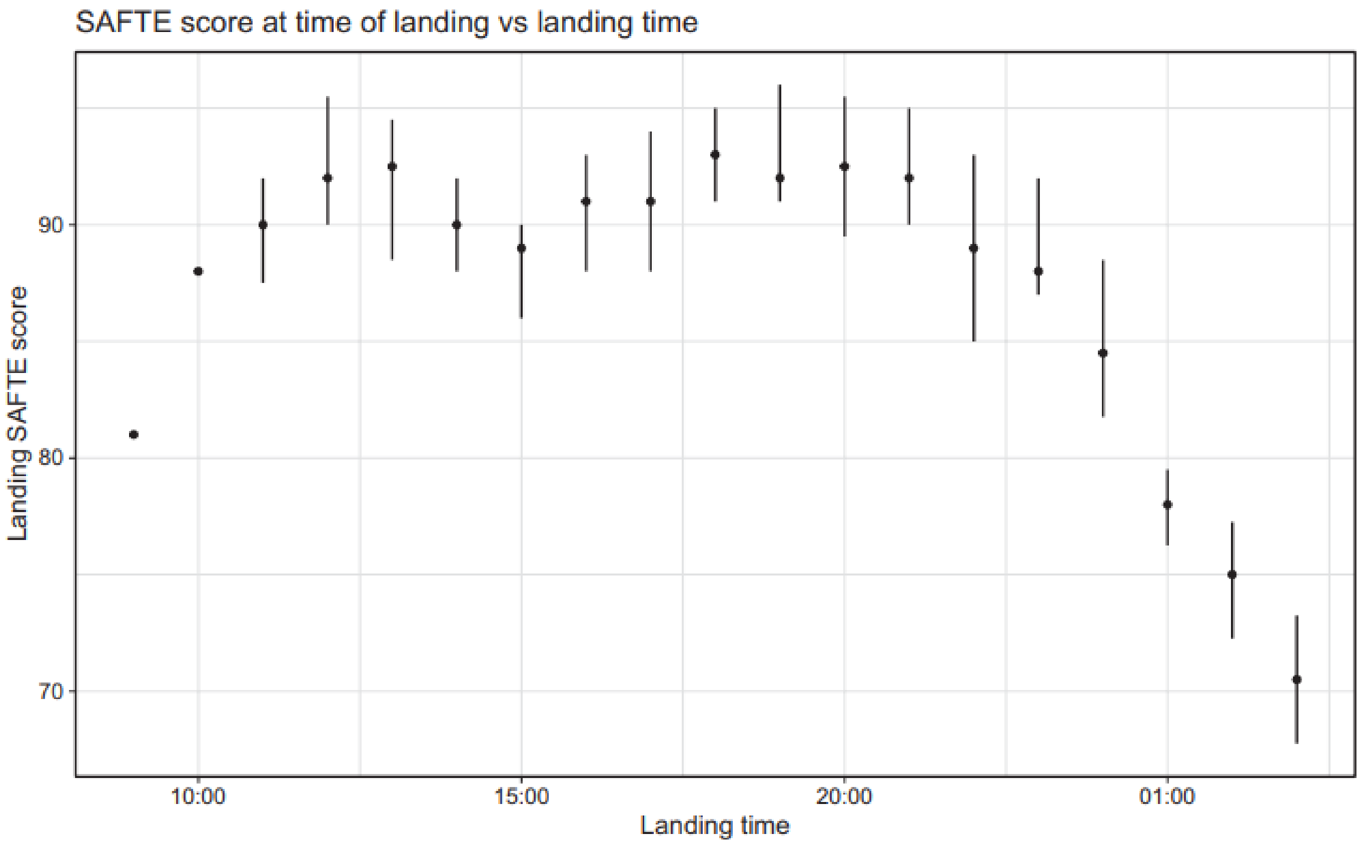
FLEET	MAXIMUM DAYS SAFE MEDIAN*	MAXIMUM DAYS WORKED MEDIAN*	MAXIMUM DAYS WORKED RANGE	% PILOTS EXCEEDING THEIR OWN LIMIT	% PILOTS WHO BUILD BACK-TO-BACK ROTATIONS
A320	6	8	4-15	67.6%	10.1%
A330	8.5	8	4-19†	27.5%	34.3%
B717	5	7	4-26	68.8%	8.2%
B737	5	7	3-18	71.2%	14.0%
B747	14	12	7-14	6.3%	43.8%
B7ER	7	6	3-15	55.6%	18.9%
B777	7	8	4-16	48.1%	18.8%
B757/767	7	9	4-22	49.6%	18.4%
MD88/90	5	7	4-23‡	75.9%	11.5%

Pilots Often Work Beyond Their Safe Rotation Limits

- Short-haul pilots **tolerate 5–6 days** but **often work longer**.
- Most pilots **(60–76%) exceeded their own fatigue limits**.
- B747 pilots manage long rotations and rarely exceed limits.
- **Few pilots choose back-to-back rotations** except A330/B747 crews.

(Gander et al., 2018)

RAPID DECLINE IN SAFTE AFTER 22:00



- Pilot cognitive performance **decreases progressively after 22:00.**
- Past midnight, SAFTE consistently signals **operational fatigue risk.**
- These effects occur even when pilots **have adequate sleep.**
- Highlights need for **FRMS in night operations.**

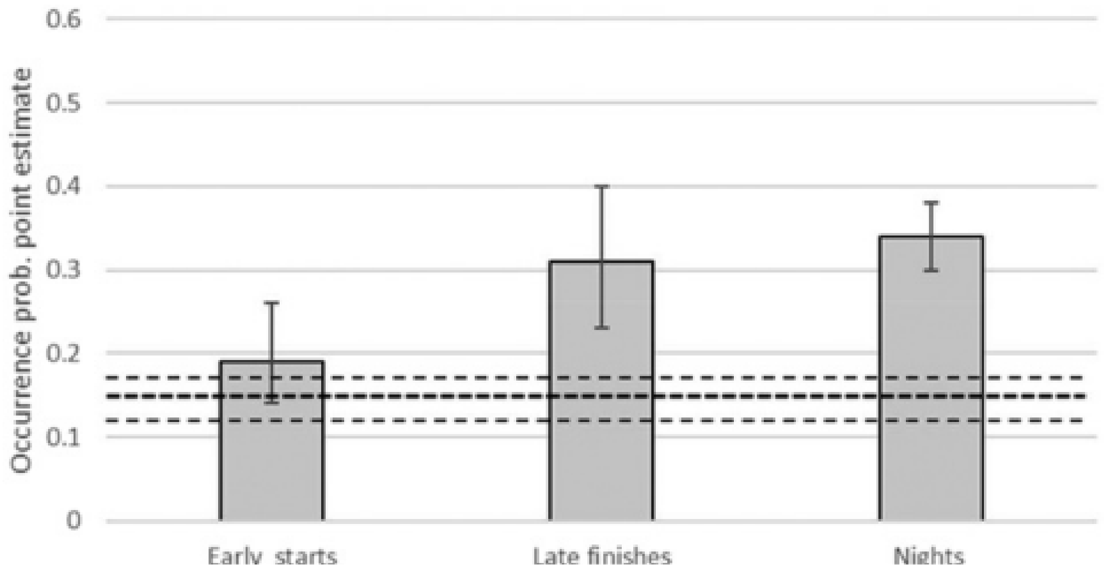
(Pelham et al., 2025)

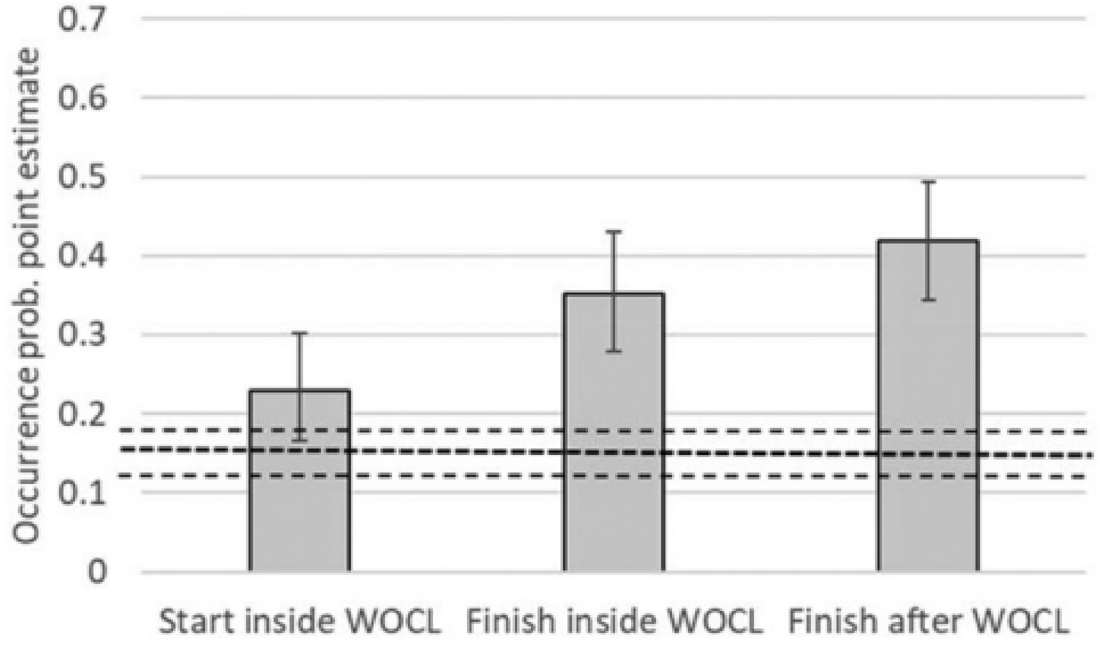
- SAFTE (Sleep, Activity, Fatigue, and Task Effectiveness Model)
- Is a **biomathematical model** that predicts a **person's cognitive effectiveness (0–100%)** based on **their sleep, circadian rhythm,** and **sleep pressure.**

FATIGUE PATTERNS ACROSS DUTY TYPES

- **Night and late-finish** duties show the **highest fatigue (~0.4)**
- **Early starts only slightly** increase fatigue **compared to day duties.**
- Fatigue is **highest when flights finish after the Window of Circadian Low (WOCL).**
- **WOCL timing—not duty length—is the strongest predictor of fatigue.**

(Sallinen et al., 2020)



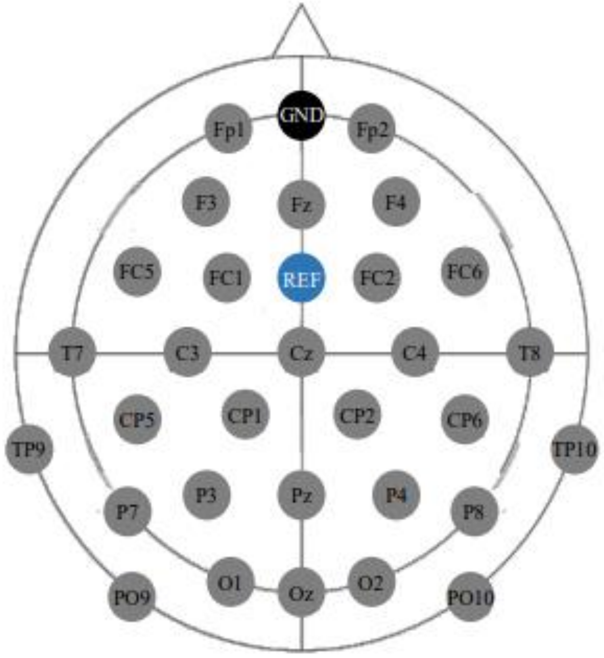


COUNTER MEASURES THAT WORKS

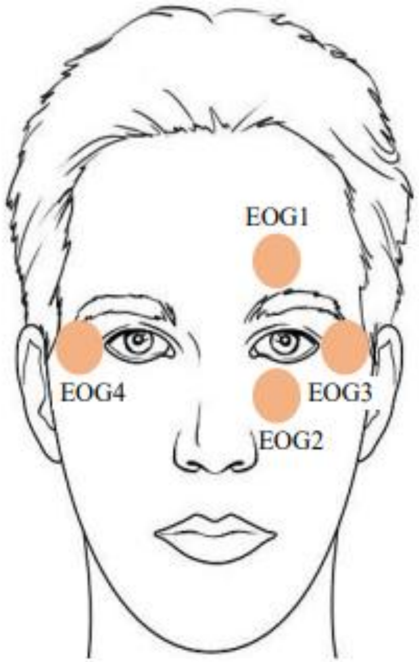
- Controlled Rest
- Caffeine +Naps
- Light Exposure
- Scheduling Reforms
- Pre-flight sleep strategies
- FRMS integration in SMS

(Sharma, 2024) & (Wingelaar-Jagt et al., 2021)

Fatigue Induction Protocol in Simulated Night Flight

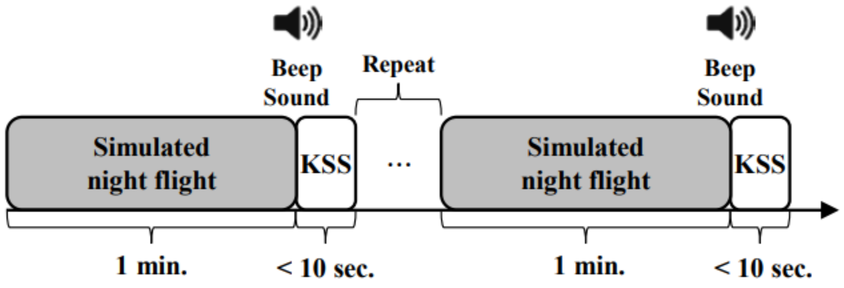


Location of EEG channels



Location of EOG channels

Electro Oculography



- level 1: extremely alert
- level 2: very alert
- level 3: alert
- level 4: rather alert
- level 5: neither alert nor sleepy
- level 6: some signs of sleepiness
- level 7: sleepy, but no difficulty remaining alert
- level 8: sleepy, some effort to keep alert
- level 9: extremely sleepy

Karolinska Sleepiness Scale

(Sauvet et al., 2024)

SLEEP INERTIA SEVERITY AND DURATION

3-15 mins
- Most Severe Impairment

First 30 mins
- Significant Impairment

30 – 60 mins
- Full recovery

(Sauvet et al., 2024)

- Some **cases take over 1 hour to normalize**
- **Deep Sleep and Sleep debt prolong impairment**

FACTORS AFFECTING SLEEP INERTIA

- Prior sleep loss
- Waking from deep sleep
- Waking at the circadian low
- Long prior wakefulness
- Unpredictable awakenings
- Sleep Disorders

Impairing

- Speed/Reaction Time
- Accuracy
- Attention
- High Level Executive Functions

Decision Making
Tactical Planning
Multitasking
Problem Solving

(Sauvet et al., 2024)

INTERVENTIONS BEFORE FLIGHT

Be fit to fly

- **Treat** sleep apnea, insomnia, restless legs.
- These conditions **worsen sleep inertia by increasing baseline sleepiness.**

Avoid Sleep Debt

- Increasing **sleep duration in nights before duty reduces** risk.

Sleep Education

- Educating pilots on **sleep cycles, circadian rhythms, and nap strategy**.

Limit Wakefulness

- Example: **take an afternoon nap before a night duty.**

(Sauvet et al., 2024)

INTERVENTIONS BEFORE NAP PERIOD

DO RISK ASSESSMENT	Nap outside Circadian Night	Anticipate Wake- Ups	Use Progressive Alarms	For High Risk
• Risk factors include: • **long nap** • night-time nap • unpredictable waking • **sleep debt**	• If possible: **naps in daytime or early night** produce less inertia.	• Wake **15 min before duty to give buffer time**.	• Light-based or sound-based **gradual alarms reduce abrupt wake-ups.**	• Take caffeine before nap (caffeine-nap strategy) • Nap <**30 min to avoid deep sleep**

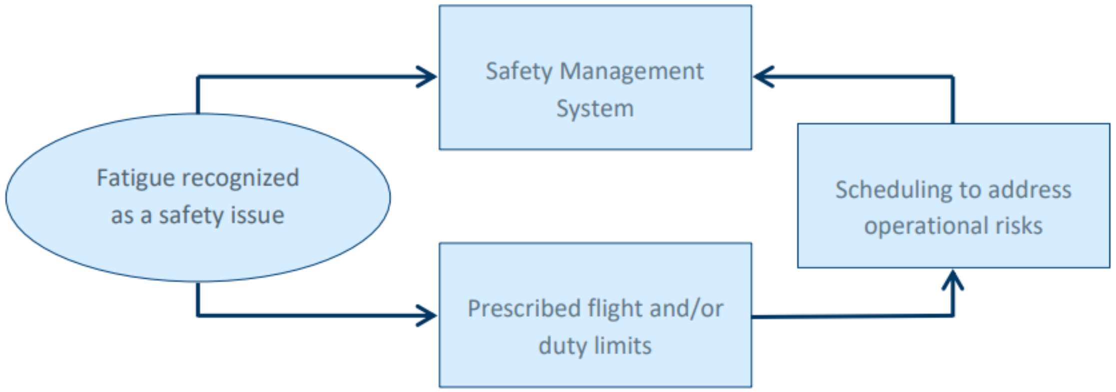
(Sauvet et al., 2024)

INTERVENTIONS AFTER NAP PERIOD

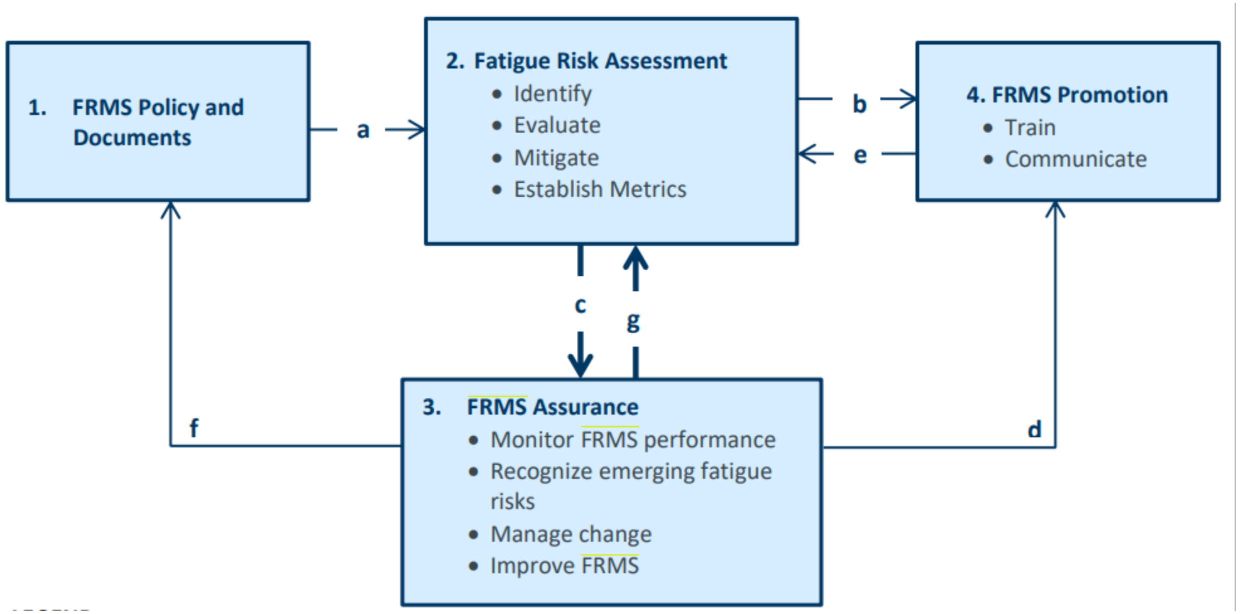
Take Caffeine (60-80mg)	Physical Exercise	Exposure to bright light	Operational Briefing
• Quickest and strongest countermeasure.	• **Increases sympathetic activity →** improves alertness.	• Improves **alertness, though effect on performance may vary.**	• Increase **situational awareness before resuming control.**

(Sauvet et al., 2024)

Evolution of Fatigue Management in Aviation



- Traditional approach uses fixed **Flight Time & Duty Time Limits (FTL).**
- **FRMS** allows **data-driven scheduling** to **manage fatigue risk.**



(ICAO, 2020)

Implemented FRMS software/system	Number of airlines	Percentage (%)
SAFTE/SAFTE-FAST	12	38,7%
Jeppesen Concert	8	25,8%
Internal FRMS (various versions)	8	25,8%
NASA Alertness Solutions + other models	2	6.5%
SIRA + biomodels	1	3.2%

Global Distribution of FRMS Tools Used by Airlines

(Cui, Wu, Tang, & Li, 2025)

- **FRMS** improves safety through **data-driven fatigue prediction.**
- SAFTE-FAST leads globally in reducing fatigue risks.
- **FRMS outperforms FTL** by identifying fatigue before it becomes a threat.

No.	Airline	Name of FRMS system/software	Year of implem entation	Advantages	Efficiency study/analysis	Obtained results
1	JetBlue	NASA Alertness Solutions	2006	Fewer operational errors	Study in Journal of Occupational and Environmental Medicine	~30% fewer errors
2	easyJet	SIRA + biomodels	2009	Less fatigue reports by pilots, reduced fatigue risk	HILAS project / easyJet FRMS case study	93% pilots less fatigued
3	Lufthansa	SAFTE-FAST	2010	Reduced fatigue risk on long-haul flights	Lufthansa FRMS internal study	Fewer delays and incidents
4	British Airways	SAFTE-FAST + internal system	2012	Reduced crew fatigue and incidents	British Airways FRMS Evaluation	Reduced fatigue incidence
5	KLM	SAFTE-FAST	2012	More efficient crew scheduling, reduced fatigue	KLM FRMS Performance Review	15% reduction in fatigue-related events
6	Qantas	Internal FRMS + SAFTE biomodel	2013	Better roster management and reduced fatigue	Qantas Fatigue Risk Management Review	Improved efficiency and safety
7	Singapore Airlines	SAFTE-FAST	2013	Reduced fatigue and increased productivity	Singapore Airlines FRMS internal review	Higher crew satisfaction, less fatigue
8	SAS	SAFTE-FAST	2013	Decreased fatigue-related incidents	SAS FRMS Safety Analysis	25% fewer fatigue-related reports
9	Southwest Airlines	NASA SAFTE model	2014	Better roster planning, fewer incidents	Southwest Airlines FRMS review	Better performance, less fatigue
10	Cathay Pacific	Jeppesen Concert	2014	Increased safety and fewer errors	Cathay Pacific FRMS Safety Report	20% fewer errors

Impact of FRMS Across Major Airlines

(Bartulović & Grgić, 2025)

11	Virgin Atlantic	Internal FRMS + biomodel	2014	Improved safety culture, better fatigue awareness	Virgin Atlantic FRMS Safety Study	Improved reporting and awareness
12	TAP Air Portugal	SAFTE-FAST	2014	Improved roster management, decreased fatigue	TAP Air Portugal FRMS Safety Study	22% reduction in fatigue-related incidents
13	Emirates	Jeppesen Concert	2015	Fewer fatigue complaints and improved safety	Emirates FRMS implementation report	Improved crew performance
14	Korean Air	Internal FRMS + SAFTE biomodel	2015	Reduced fatigue and improved roster management	Korean Air FRMS Analysis	30% reduction in fatigue
15	Aer Lingus	Jeppesen Concert	2015	More balanced rosters, reduced fatigue levels	Aer Lingus FRMS Pilot Survey	30% reduction in fatigue symptoms
16	Air France	Internal FRMS + Jeppesen Concert	2015	Improved roster optimization, better fatigue risk control	Air France FRMS Program Review	20% reduction in fatigue

(Bartulović & Grgić, 2025)

Impact of FRMS Across Major Airlines

No.	Airline	Name of FRMS system/software	Year of implementation	Advantages	Efficiency study/analysis	Obtained results
17	Etihad Airways	Jeppesen Concert	2015	Enhanced fatigue monitoring and reporting	Etihad Airways FRMS Implementation Report	20% decrease in fatigue incidents
18	Delta Air Lines	Internal FRMS + NASA biomodel	2016	Increased awareness and fewer incidents	Delta Air Lines FRM Analysis	Significant reduction in fatigue reports
19	Air Canada	Jeppesen Concert	2016	Improved safety and crew satisfaction	Air Canada FRMS Safety Study	Improved safety
20	Air New Zealand	Jeppesen Concert	2016	Reduced fatigue reports, better roster flexibility	Air New Zealand FRMS Effectiveness Study	~25% reduction in fatigue reports
21	Philippine Airlines	SAFTE-FAST	2016	Improved crew alertness, reduced errors	Philippine Airlines FRMS Study	20% fewer fatigue incidents
22	Japan Airlines	Internal FRMS system	2017	Increased safety, fatigue reporting	JAL Fatigue Risk Management Program	Increased reporting and incident reduction
23	Alaska Airlines	NASA SAFTE-FAST	2017	Better crew efficiency and reduced fatigue	Alaska Airlines Fatigue Management Study	Improved crew efficiency
24	Turkish Airlines	SAFTE-FAST	2017	Enhanced alertness, fewer fatigue-related errors	Turkish Airlines FRMS Implementation Review	20% reduction in errors
25	Avianca	Jeppesen Concert	2017	Better fatigue risk controls, less fatigue complaints	Avianca FRMS Implementation Review	25% reduction in fatigue symptoms
26	Ryanair	Internal FRMS	2018	Reduced fatigue on short-haul flights	Ryanair FRMS Pilot Survey	25% reduction in subjective fatigue

Impact of FRMS Across Major Airlines

(Bartulović & Grgić, 2025)

Bio - mathematical Fatigue Models in Aviation

- Predictive Fatigue Assessment
- Training and Education
- Supporting irregular operations.
- Optimizing rest/napping strategies
- Support FRMS decisions beyond prescriptive FTL.
- Compare duty rosters and identify high-risk fatigue windows.
- Individual Fatigue Prediction e.g. phone apps
- Can be used in Safety Investigations

(IATA, n.d.)


ASANTE SANA