LENS: Applied Circadian Science Framework for Lifestyle Fatigue Risk Management Strategies

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***Abstract*—Shiftwork underpins most modern round-the-clock operations: an estimated 40 million people in the United States work non-standard shift schedules across industries as diverse as railroads, airlines, hospitals, mining, and oil and chemical refineries, with the shift-work sector expanding roughly 6% per decade. Since the 1950s, science has consistently shown that shiftworkers suffer significantly more physiological illness than regular day workers, including elevated rates of cardiovascular disease, gastrointestinal disorders, and sleep disorders. The U.S. National Institute for Occupational Safety and Health (NIOSH) has identified worker education as among the most effective tools for mitigating shiftwork hazards, yet most organizations deliver only generalized, infrequent annual training that is not tailored to an individual's actual roster and is therefore difficult to retain or apply.**

LENS — Lifestyle Education & Notifications for Shiftworkers — addresses this gap by taking an organization's actual work schedules and generating schedule-specific, graphic, easy-to-follow lifestyle recommendations on a continuous, year-round basis rather than through a single annual session. The system is built on two proprietary computational platforms: ARC (Activity-Rest Cycle), which models fatigue risk across an individual's actual 24-hour work/rest pattern, and FIRM (Fatigue/Roster Risk Index Module), which quantifies roster-level fatigue risk through bio-mathematical modeling. Together, these platforms convert circadian and sleep science into a Risk-Informed Performance-Based (RIPB) system for fatigue management across 24/7 industries.

***Keywords*—.**

I. Introduction

Modern societies rely on continuous operations in many diverse industries. Operating 24/7 maximizes facility utilization, improves efficiency, and reduces start-up, shutdown, and capital costs, but it requires an increasing share of the workforce to remain productive outside natural sleep/wake windows. Estimates place the U.S. non-standard-shift workforce at roughly 40 million people. Shiftwork, and the resulting sleep deficiency, has been identified as the leading source of fatigue relatede costs in the U.S. economy.

Because fatigue costs are diffuse — spread across lost productivity, absenteeism, turnover, healthcare, and accidents — different analyses using different time periods and methodologies arrive at different headline totals. Three widely cited estimates frame the scale of the problem. These figures are not three measurements of the same quantity — they differ in scope (shift-work-specific costs versus economy-wide sleep-deficiency costs), population (shift workers only versus the general workforce), and vintage. Read together, they bound the problem from roughly $200 billion to over $400 billion annually, depending on scope.

More recent employer-facing estimates reinforce the scale of the problem: the National Safety Council estimates fatigue costs employers on the order of $136 billion a year in health-related lost productivity, with tens of millions of Americans affected by sleep disorders. Analyses associated with Brigham and Women's Hospital and the NSC indicate that sleep-deficiency costs in the U.S. have been estimated to exceed $410 billion in a single year, and that a 1,000-employee employer can lose roughly $1+ million annually to fatigue-related absenteeism, presenteeism, healthcare, and related costs.

Employers have a duty of care to design safe 24/7 work, policies, and practices that allow recovery, adequate sleep, and alertness restoration. Poor schedules and policies will have built-in, inherent fatigue, so it is up to the employers to address these issues. Employees share responsibility to manage lifestyle so they report fit for duty. Poor lifestyle choices lead to increased fatigue, so it is up to the employees to make wise lifestyle choices. Fatigue management is therefore a shared company–employee obligation.

Shiftwork companies typically provide training for their employees, usually on an annual basis, that teach principles that lead to lifestyle choices which reduce shiftwork fatigue. It is up to the employee to apply these principles on a daily basis.

The problem is exacerbated by absenteeism, callouts, and temporary schedule changes. Consequently, each employee has unique variations on the schedule, and hence the company-wide planned implementation of the lifestyle choices does not always apply.

The alternative is a risk-informed performance-based (RIPB) approach: rather than counting hours, RIPB models the interaction between an individual's actual work/rest pattern and established circadian principles to flag fatigue risk proactively and to guide targeted, low-cost lifestyle countermeasures. Organizations that equip staff and managers with easy-to-use, science-based fatigue and lifestyle tools can reduce fatigue-related error, accident, and liability exposure; improve performance, morale, and retention; fulfill duty-of-care expectations with greater flexibility than pure prescription; and differentiate as employers that invest in staff health, wellness, and family support.

This paper introduces Lifestyle Education & Notifications for Shiftworkers (LENS), which is designed to flag problems, prescribe actionable fixes, and create feedback for continuous improvement.

II. Methodology

Enumerating principles, or rules, is not an effective method for educating employees regarding lifestyle choices. Presenting these rules in annual training is useful, but having employees correctly apply what are sometimes contradictory rules months after training is not reliable. The approach used by the LENS system is to have the tools apply these rules, then display the results in an easy to understand graphical format, showing the key choices to be made each day. The following steps were performed to construct the LENS system:

• Determine the industry best-practices through literature research and by examining training material from several companies,

• Distilling the information into a set of strategies,

• Development of a graphical representation for the implementation of each strategy,

• Design of a comprehensive set of templates, where each template represents roughly one calendar day, and where these templates can be combined to fit essentially any shiftwork schedule, and

• Deriving tools that incorporate the LENS technology.

The following sections document these steps.

II.A. Research

The reference section of this document lists the primary sources used to provide the industry best practices regarding the lifestyle choices for shiftwork. Additional sources were training materials used by various companies or by various consulting services.

II.B. Strategies

The principles gleaned during the research phase were aligned, unified, and combined to form a set of 12 strategies, which are summarized in Table 1. These strategies can be applied to an actual schedule to produce a set of recommendations for the employee. Typical recommendations are:

• When to sleep, when to awaken, and when to take a strategic nap,

• When to eat meals, and the type of meal to be used,

• When to exercise, and

• When to curb the consumption of caffeine.

II.C. Activity-Rest Cycle

The graphical representation chosen for the LENS technology is the Activity-Rest Cycle (ARC) model.

The ARC model plots an individual's day- and night-shift work schedule against a standard 24-hour timeline and overlays recommended timing for sleep, naps, meals, exercise, and caffeine use, together with fatigue-zone markers indicating periods of elevated within-shift alertness risk. A full ARC output for a 12-hour, 7-day/24-hour fast-rotating schedule illustrates how the model differentiates day-shift and night-shift instructions — including anchor sleep, transition and recovery days, and isometric versus aerobic exercise windows — across a full roster cycle.

Fig. 1 shows the ARC Model for a typical 28-day shiftwork schedule, with 12-hour shifts that start at either 7:00 am or 7:00 pm. The green regions in the diagram represent work shifts, the blue regions are suggested sleep times, and the red regions represent periods of time while the employee is at work when fatigue is expected to be higher than usual.

ARC is a worker facing "what to do when" expression of LENS — bridging diagnosis and daily behavior. Its color-coded, one-page graphic format is intentionally accessible to non-expert end users, and each planner is customized to an organization's actual shift patterns.

Strategy	Definition (condensed from LENS program materials)
Sleep Zones	Recommended timing and duration for restorative sleep, identified individually for each shift and rest day to promote alertness, health, and quality of life.
Sleep Inertia	The 15–60 minute window of reduced alertness and capacity immediately after waking; the ARC model flags this period as a heightened-risk interval for task performance.
Anchor Sleep	A consistent block of sleep set before and after night shifts to stabilize the overall sleep pattern and support restorative (deep-sleep) recovery.
Nap Zones	Recommended windows (typically 10–30 minutes, up to 1.5 hours) for short naps to offset the afternoon alertness dip or recharge alertness during night shifts, while avoiding deep sleep and resulting sleep inertia.
Fatigue Zones	Periods within a shift carrying an elevated risk of dangerous alertness dips, flagged so that isometric exercise or timed caffeine use can be applied.
Food Selection / Grazing	Meal type and timing matched to shift phase (protein-based meals before night shifts, light meals after day shifts, smaller "grazing" portions) to reduce fatigue and support digestion.
Sleep Hygiene	A pre-sleep routine (dimmed light, reduced screen use, relaxation) performed for roughly one hour before day or night sleep to improve sleep quality.
Yearly Planning	Calendar-based identification of optimal, lower-fatigue days for date-specific personal or family events, based on the individual's roster cycle.
Caffeine Timing	Guidance on curbing caffeine intake several hours before scheduled sleep (caffeine effects can persist up to five hours) while permitting use ahead of a fatigue zone.
Exercise (Isometric / Aerobic)	Short isometric exercise during fatigue zones to maintain alertness, and aerobic exercise scheduled during non-working hours to support overall fitness and sleep quality.
Transition Days	The final full rest day before beginning a run of night shifts, used to phase sleep timing gradually toward the night-shift pattern.
Recovery Days	The first full rest day after a run of night shifts, used to phase sleep back toward a day-oriented pattern and address accumulated sleep debt.

Table 1: The 12 LENS Strategies.

II.D. Templates

A series of 'templates' were constructed, with each template consisting of either a 12-hour, 24-hour, or 36-hour portion of time. Most templates cover a 24-hour period. These templates were designed to cover all possible variations of 12-hour shiftwork, so that any planned schedule could be represented using a sequence of these templates. In addition, any possible combination of callouts and absenteeism could also be represented by

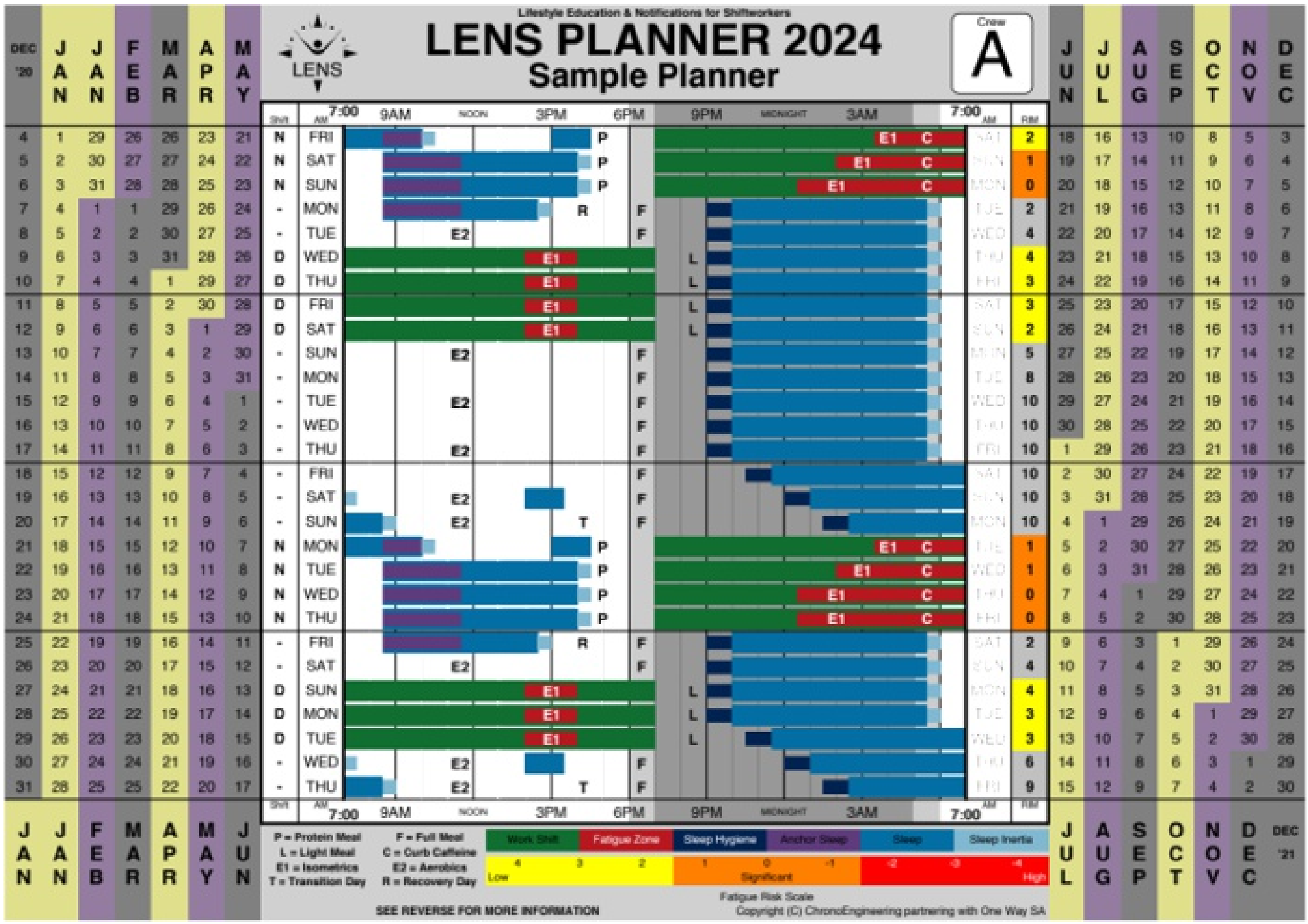

Figure 1: Sample LENS 24/7 Lifestyle Planner. Color-coded shift, sleep and fatigue zones, as well as meal, exercise events, are shown.

a sequence of templates.

The lifestyle strategies were applied to each of the templates, so that each template contains the ARC regions and events that are important for that portion of the schedule. Note that the templates are parameterized based on the start and end times of the work shifts. The timing of some events are keyed to a particular time of day, to reflect circadian considerations (such as nap or exercise annotations) or to adapt to social convensions (such as meal times).

The result is that for any shiftwork schedule, including any variations and customizations of those schedules, can be converted to a template sequence, and through this sequence of templates the lifestyle recommendations can be directly seen.

II.E. Implementations

Given the strategies and the templates, guidance can be provided for any schedule. The following solutions have been built to make these results accessible to employees.

II.E.1. Yearly planners

These are based on the planned schedule and are used for a family's long-range planning purposes. Fig 1. shows one of these yearly planners. These show a worker's schedule as planned at the start of the year, and does not reflect any absenteeism, call-out, or schedule changes.

Posted on a fridge or computer, planners help workers and families jointly confirm best nap and sleep timing (phase advance or delay) to obtain optimum sleep quality and duration for each shift start and rest day — specifically to:

- Address shift-work sleep restriction that causes fatigue and impairs performance
- Promote sleep hygiene on work and rest days for quality of life and wellness
- Show day anchor sleep times for delta / stage-4 sleep, critical for alertness recuperation and night-shift readiness

• Flag shift-specific fatigue zones so ARC instructions can target predicted at-work risk, including micro-sleep avoidance

Planners also serve as tangible expressions of management commitment to staff health and wellness throughout the year, functioning as practical tools and valued employee/family gifts.

II.E.2. Train-The-Trainer Slide Decks

These are custom slide decks produced from the company's actual planned schedule, and describes the principles and strategies as they apply to the schedule. Company's use these slides as the backbone of the annual training. These slides show the company's actual yearly planners, so the employees can see how the various lifestyle principles and strategies apply to their actual schedule, not to some hypothetical or generic schedule.

II.E.3. Family Guides

The family guides help the families to understand the yearly planners, and also to understand the principles and strategies that were incorporated into the planners, to reduce the number of mistakes a family might make when not following the planners.

II.E.4. Mobile Application

Mobile applications are implemented both for iOS and Android. An employee enters the base schedule into the app, and then can scroll to any day of the year to see not only the work schedule, but also the lifestyle choices that are optimized for that day.

Using the calendar view, the employee can quickly edit the schedule to add any call-out days, remove any vacation or sick days, or make other schedule modifications. In addition, shift swaps can be tested to see the ramifications not only to the lifestyle activities, but also to see how the fatigue score would be affected. The app, using the templates, can quickly display how the lifestyle recommendations change to fit the new schedule.

II.E.5. Phone Alerts

The mobile application includes customizable alerts that the user can enable to send reminders for specific strategy events. If the employee has trouble remembering some actions, such as when to curb caffeine, or when to perform isometric exercises, these alerts can be enabled.

II.E.6. In-App Training

The mobile application includes training material, similar to the content of the annual training sessions, so the employee has instant access to the training material.

III. Results

Baseline Motivation: Cross-Industry Lifestyle-Training Survey

Program materials cite a 2003 industry survey finding that 77.7% of shiftwork facilities offered no lifestyle training to shift workers, 17.6% trained shift workers alone, and 4.7% additionally involved workers' families. Facilities that provided training reported lower annual turnover (7.6% versus 11.4%) and lower absenteeism (4.8% versus 6.3%) than facilities without training, corresponding to an estimated combined saving of $1,892 per employee per year ($952 from reduced turnover and $940 from reduced absenteeism). This survey establishes the baseline gap in shift-worker lifestyle support that LENS is designed to close.

Case Study: Kumba Iron Ore, Sishen South (Kolomela)

As part of a Bio-Roster Focus Group engagement at Kumba Iron Ore's Sishen South operation (Kolomela), LENS practitioners administered a roster-preference questionnaire to the combined Sishen South workforce. In response to the question "Do you feel that some type of training on how to better manage a shiftwork lifestyle would make it easier to cope with the special challenges of shiftwork rosters?", 88.1% of respondents answered yes. In response to a separate question on receptiveness to external expertise ("How receptive are you to the company bringing in 'Roster Experts' to help you determine your future shift roster?"), 82.5% of respondents indicated they were "very receptive" or "receptive."

Case Study: Wessels Mine FIRM Roster Audit

A FIRM audit conducted at South32's Wessels Mine illustrates the practical value of moving beyond simple hour-count rules toward graded, roster-specific fatigue quantification: a schedule that complied with standard maximum-hours and minimum-rest requirements nonetheless placed more than a third of its cycle in a Significant-to-High fatigue-risk band. This finding is directionally consistent with the peer-reviewed finding that accident risk rises progressively across successive night shifts even when total hours are held constant, and it reinforces the rationale, articulated in LENS program materials, for supplementing prescriptive hour limits with physiology-informed roster scoring such as FIRM.

Taken together, these field materials — drawn from LENS/Bio-Roster deployments in the mining sector, including at Kumba Iron Ore (Sishen South / Kolomela), a South32 operation (Wessels Mine), and BHP Billiton's Metalloys facility — suggest that shift workers themselves recognize a gap in lifestyle and roster-design support and are broadly receptive to structured, evidence-based intervention, consistent with the broader literature on shift-worker support gaps in which the majority of shiftwork facilities historically provided no lifestyle training at all.

IV. Discussion

LENS implements an RIPB safety philosophy: rather than relying solely on static rules, it uses measured/projected risk (FIRM2) and performance-oriented interventions (ARC, strategies) with feedback so workers and managers can improve scores and lifestyle adaptation over time. This RIPB framing is presented in the LENS field literature as a direct alternative to hour-count compliance regimes, and field evidence (the Wessels Mine FIRM/RIM audit) illustrates why a purely hour-based rule can miss meaningful roster-level risk that RIPB scoring detects.

The system rests on established determinants of alertness — circadian phase, prior sleep, and time awake — and on decades of experimental and field research into shift length, timing, and rest. National occupational health authorities continue to emphasize that shift work and long hours elevate risk through circadian misalignment, sleep deprivation, and related pathways, and that countermeasures (naps, caffeine, education, schedule design) work best as part of structured fatigue risk management, not as isolated tips.

LENS differentiates from conventional, hours-based fatigue controls across several practical dimensions. It substitutes physiology-informed risk scores and strategies for hours limits, engages staff, managers, and families rather than compliance officers alone, delivers continuous daily/yearly visual planners rather than occasional policy training, enables comparable fatigue scores across scheduling options rather than relying on rules of thumb, produces actionable prescriptions rather than constraints alone, and is customized to each organization's patterns and branding rather than generic.

The 24/7 economy cannot function without shift work — but it also cannot afford to treat human alertness as infinitely flexible. Circadian biology, sleep restriction, and cumulative roster design interact to create fatigue risk that prescriptive hour rules alone have never fully controlled. The resulting burden — accidents, lost productivity, health costs, turnover, and eroded quality of life — remains one of the largest unmanaged or under-managed operational costs in continuous industries, conservatively estimated in excess of $200 billion annually in the United States alone, with some broader analyses placing the figure well above $400 billion.

LENS offers a coherent alternative: a Risk-Informed Performance-Based system that combines bio-mathematical roster intelligence (using the FIRM2 biomathematical model) with worker- and family-facing lifestyle tools (the ARC model, the twelve lifestyle strategies, and the 24/7 Lifestyle Planner). Field materials from mining-sector deployments indicate that shift workers are receptive to structured lifestyle and roster-design support, and that FIRM2 analysis can surface fatigue risk in rosters that would otherwise appear compliant under standard hour-count rules. These findings, while encouraging, rest on unpublished internal and client data that warrant independent, peer-reviewed validation — a priority for continued development of the program.

LENS is built to be scientifically grounded, operationally practical, customizable, and economical — helping organizations fulfill duty of care while preserving the flexibility competitive 24/7 operations require. Given that fatigue-related costs to the U.S. economy are conservatively estimated in excess of $200 billion annually, continued development and independent evaluation of RIPB-style tools such as LENS represent a worthwhile complement to existing prescriptive fatigue regulation.

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