SAFTE-FAST

SAFTE-FAST Combined Capacity Metric

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Introduction

Biomathematical models are widely used in the aviation, rail, and shiftwork industries to assess fatigue risk during operations. Many models, including the SAFTE model, are fundamentally influenced by the two-process model of sleep regulation, which estimates fatigue in relation to prior sleep duration, and circadian rhythm/time of day (Borbely 1982, Mallis, Mejdal et al. 2004). However, fatigue can also be due to workload. In SAFTE-FAST, workload associated with a duty, or series of duties, is conceived as a series of operational factors that impact the cognitive demands on the pilot. Operational factors may be any predictable condition that the model can derive from the input information. In operations, it is not uncommon for high workload and low alertness to co-occur, creating a compound fatigue risk. High workload alone is seldom a fatigue hazard if a person is alert and able to handle work demands. Relatively high workload is a fatigue risk when it is combined with relatively low alertness, represented by low effectiveness and reservoir.

This white paper describes a metric within SAFTE-FAST called Combined Capacity that indicates areas of high compound fatigue risk. The Combined Capacity metric represents cases in which work demands exceed cognitive capacity. Combined Capacity is an average of Effectiveness, Sleep Reservoir, and Workload. Low Combined Capacity scores indicate cases of high compound fatigue risk.

SAFTE-FAST Fatigue Risk Metrics

Fatigue is a general term used to describe low alertness, feelings of tiredness, or reduced cognitive ability. Fatigued individuals are less alert, have reduced ability to process information, and have slower reaction times than usual, which can lead to operator errors and procedural violations which can ultimately result in costly damage to people and property (Gaines, Morris et al. 2020).

Sleep Reservoir

Fatigue is heavily related to prior sleep duration. In SAFTE-FAST, the capacity to perform cognitive work as a function of prior sleep is computed as Sleep Reservoir. Under fully rested, optimal conditions, Sleep Reservoir would equate to a score of 100. A score of 75 is roughly equivalent to a cumulative sleep debt of eight hours or the loss of one full night of sleep for the average person (Hursh, Redmond et al. 2004, Paul, Hursh et al. 2020). A Sleep Reservoir score at or below 75 is considered a threshold for fatigue risk in SAFTE-FAST.

Effectiveness

While a Sleep Reservoir score below 75 is an indicator of fatigue risk, other factors can affect performance as well, such as time-of-day, sleep inertia, or workload. Time of day relates to a person's 24-hour cycle (circadian rhythm) of alertness. Reduced cognitive ability is greatest during the windows of circadian low (WOCL). The primary WOCL occurs at night when physiological sleepiness is greatest and performance capabilities are lowest, roughly between the hours of 0200 to 0600 (Dinges, Graeber et al. 1996). The reduction in alertness during the WOCL can be exaggerated by inadequate prior sleep (FAA 2010). Operators may also experience low alertness, reduced cognitive ability, or grogginess upon waking from sleep. This phenomenon is known as sleep inertia (Wertz, Ronda et al. 2006). The effects of sleep loss, time of day, and sleep

inertia are combined in SAFTE-FAST to predict Effectiveness.

Effectiveness represents the speed of performance on the Psychomotor Vigilance Test (PVT), scaled as a percent (%) of a fully rested person's normal best performance (Rangan and Van Dongen 2013). Effectiveness scores range from 0 to 100; scores below 77 indicate a significant risk for fatigue, equivalent to 18.5 hours of continued wakefulness for a fully rested person or a blood alcohol concentration of 0.05 g/dL (Dawson and Reid 1997). Effectiveness scores below 77 are considered a fatigue risk by the Federal Aviation Administration guidelines for airline pilots (FAA 2012).

Effectiveness Score	PVT Lapse Likelihood	Hours Awake	BAC Equivalent
98	0.2	14:00	
94	1.0	15:10	
90	1.5	16:00	
80	3.0	18:00	
77	4.0	18:30	0.05
70	5.0	21:00	0.08
69	5.4	22:00	
60	8.0	40:50	
50	12.0	42:30	
40	16.0	64:00	

Workload

Profiled Workload rules are first needed in order to properly use the Combined Capacity metric. Fatigue can also occur because of workload. Workload is the mental or physical activity demanded of an operator in relation to a duty or series of duties. Workload factors are additive over time, so there is no arbitrary limit to the range of workload scores. Raw workload values are normalized to a 100-point scale. This is done by setting a maximum value in the workload parameters and all "raw scores" are divided by that maximum, converting the scale to percentages of the maximum, resulting in a normalized score between 0-100. Normalized Workload scores range from very low workload (0) to very high workload (100) as shown in the table below.

Fatigue Risk Level	Normalized Workload Score
Very Low	0-20
Low	21-40
Medium	41-60
High	61-80
Very High	81-100

Combined Capacity

In SAFTE-FAST, Workload is a separate calculation from Effectiveness while Sleep Reservoir is one of the factors used to compute Effectiveness along with time of day and sleep inertia. Workload is a measure of "demands on the operator" while Effectiveness is a measure of "capacity to react to demands". An operational hazard is created when there is a "mismatch" between these two factors, that is, high workload at the same time Effectiveness is low. To state it another way, when alertness is low, a person is more vulnerable to making a mistake when workload is high because capacity is not sufficient to handle the load.

Understandably, users may want to reference a single metric that summarizes the overall fatigue risk rather than examining Effectiveness, Sleep Reservoir, and Workload separately. This is the logic behind the Combined Capacity Metric in SAFTE-FAST. The Combined Capacity Metric averages three performance metrics: Effectiveness, Sleep Reservoir, and Workload. Effectiveness, Sleep Reservoir, and normalized Workload all use a 0 to 100 point scale. However, while higher scores (i.e., 100) indicate greater capacity and lower fatigue risk with Effectiveness and Reservoir, the opposite is true of Workload. Higher scores in the Workload metric indicate more work-related demands and thus, less cognitive capacity and greater risk. To reconcile the differences in scale directionality between Effectiveness, Reservoir, and Workload, the Workload scale is inverted when computing Combined Capacity.

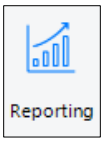
Combined Capacity uses a 100-point scale and reflects the person's cognitive capacity reduced by cognitive demands of work-related demands in addition to physiological fatigue. High workload alone is seldom a fatigue hazard if a person is alert and able to handle work demands. Relatively high workload is a fatigue risk when it is combined with relatively low alertness. The Combined Capacity metric represents cases in which work demands exceed cognitive capacity. Higher scores for Combined Capacity (i.e., 100) indicate greater capacity and lower fatigue risk while lower scores (i.e., 0) indicate less capacity and higher risk.

Guide to Using Combined Capacity

The Combined Capacity metric is intended to highlight fatigue risk associated with high workload and low alertness. Users should establish profiled workload rules prior to using the Combined Capacity metric. Workload rules can be set using the Workload Calculator in consultation with SAFTE-FAST product support and scientific teams. Combined Capacity Minimum, Combined

Capacity Minimum Crewing, and Combined Capacity Minimum Critical can be exposed using the SAFTE-FAST Column Chooser.

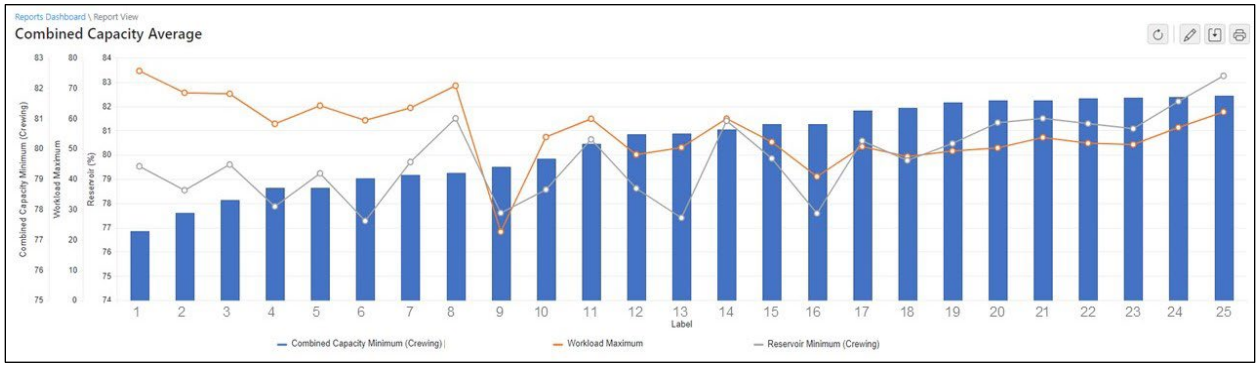
Schedules can be sorted by Combined Capacity Minimum by right-clicking the column and selecting "Sort Ascending" or "Sort Descending". The lowest Combined Capacity Minimum scores indicate the highest fatigue risk; selecting "Sort Ascending" will reorder schedules based on the lowest Combined Capacity Minimum scores.



Combined Capacity can also be examined in the Reporting Tool. Launch the Reporting Tool using the icon on the top bar menu. Add a report to examine Combined Capacity across schedules or duties as well as in relation to Workload and Sleep Reservoir. Consult a SAFTE-FAST product support specialist for more information about adding a Combined Capacity report to the default report library.

The purpose of the report which displays Combined Capacity in relation to Workload and Sleep Reservoir is to examine whether low scores are driven primarily by sleep loss, high workload, or both. As shown in the example below, Combined Capacity is displayed as a bar chart (in blue). Workload (in orange) and Sleep Reservoir (in gray) metrics are overlaid as line charts. The duties in this example that have the highest fatigue risk are those with the lowest Combined Capacity metric, as indicated by the shortest bars. Duties in this example are ordered from lowest Combined Capacity score (lowest risk) to highest Combined Capacity scores (lowest risk). The example shows that duties with the lowest Combined Capacity scores also had the very high Workload (above 81) and relatively low Sleep Reservoir (below 80). Generally speaking, duties with higher Combined Capacity scores have higher Sleep Reservoir or lower Workload, but this is not the case for every duty. In the example below, Duty 9 has higher Combined Capacity on average compared to Duty 8 despite having much lower minimum Sleep Reservoir. The Combined Capacity score is higher because Workload is lower for Duty 9 compared to Duty 8. The primary fatigue risk for Duty 9 is related to insufficient sleep, while the risk for Duty 8 is related to workload.

Example of Combined Capacity with Workload and Sleep Reservoir SAFTE-FAST Report



Discussion

Combined Capacity is a way of quantifying fatigue risk that arises from multiple sources of fatigue—namely, Sleep Reservoir, Effectiveness, and Workload. This singular metric allows SAFTE-FAST users to see a snapshot of compound fatigue risk but is not a replacement for Effectiveness, Sleep Reservoir, or Workload metrics. Duties or schedules that have low Combined

Capacity should be examined in greater detail to determine whether fatigue risk is due more to demands on the operator or the operator's physiological capacity to react to those demands in order to determine the most appropriate mitigation strategy.

Take Aways

- The Combined Capacity metric averages Effectiveness, Sleep Reservoir, and inverted Workload to provide a singular snapshot of compound fatigue risk.
- Lower Combined Capacity scores indicate higher fatigue risk.
- Schedules or duties with low Combined Capacity scores should be analyzed in greater detail to determine the best fatigue mitigation strategies.

Be aware that biomathematical models cannot account for individual differences in fatigue or alertness, such as the presence of sleep disorders, use of caffeine or other stimulants, or chronic sleep debt.

Resources

For more information about fatigue estimation using SAFTE-FAST or assistance using SAFTE-FAST to support an investigation, please refer to the SAFTE-FAST user manual, visit https://www.saftefast.com, or contact info@saftefast.com.

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