

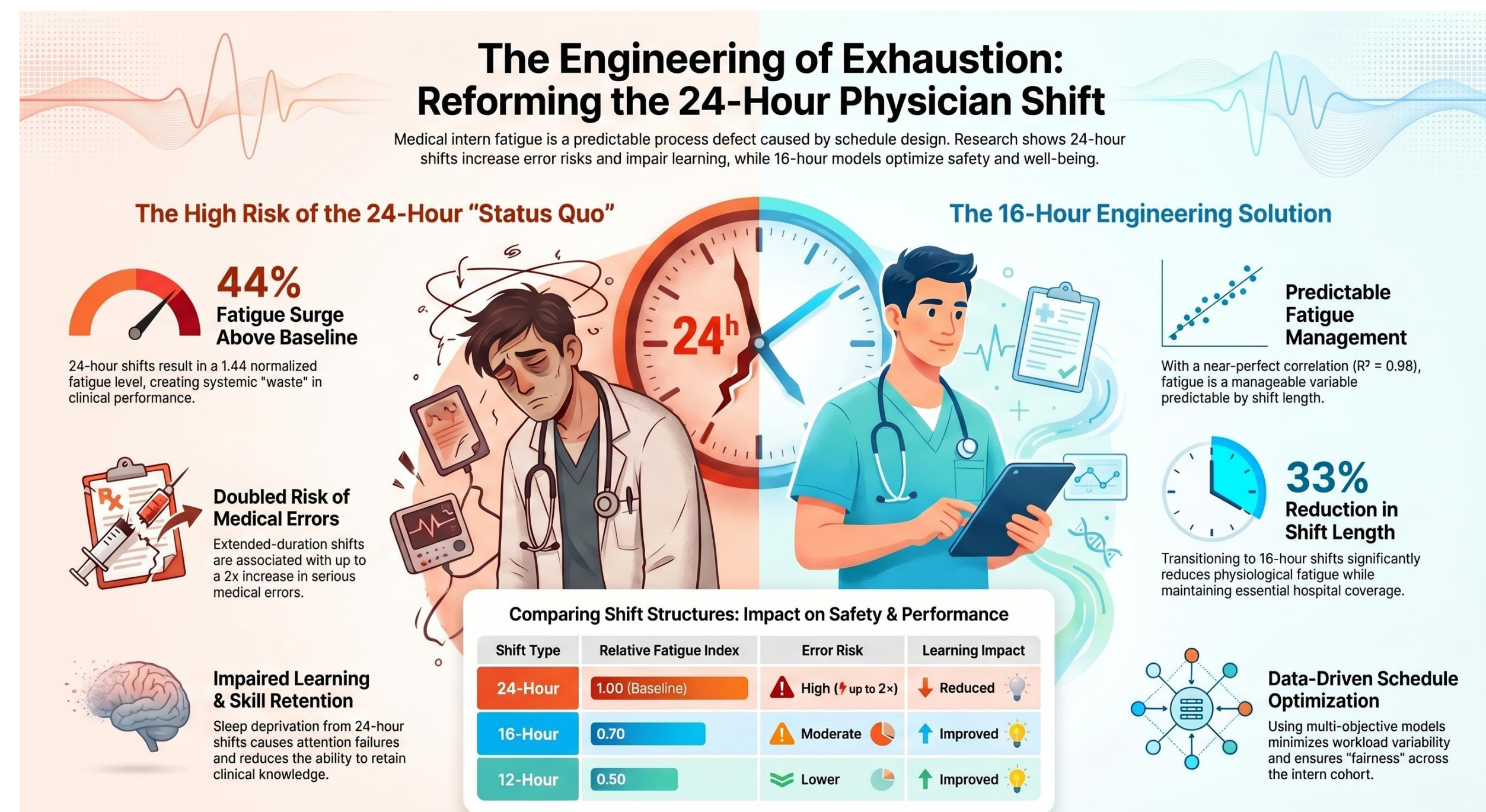
AN ENGINEERING APPROACH TO REDUCING PHYSICIAN FATIGUE AND ENHANCING LEARNING

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Abstract

Medical intern schedules frequently involve 24-hour shifts, leading to systemic fatigue and potential medical errors. This study applies Lean Six Sigma and operations research to optimize scheduling by treating fatigue as a predictable process variable. A multi-objective model was developed to minimize cumulative fatigue and workload variability for 18 interns. Fatigue was quantified via a weighted composite score across 24-hour, 16-hour, and 12-hour shift scenarios, maintaining ACGME compliance and hospital coverage. Analysis of the 24-hour model showed a near-perfect correlation between hours worked and fatigue ($R^2 = 0.9988$), with a mean normalized fatigue of 1.44 (44% above baseline). Transitioning to a simulated 16-hour model reduced normalized fatigue to 1.20 and reduced workload variability. Fatigue was shown to be a predictable output of schedule design. Transitioning to 16-hour shifts mitigates systemic "defects," optimizing patient safety and resident well-being through data-driven process stability.



Background

• Intern-year physicians provide continuous patient care while developing core clinical skills. In many hospitals in Puerto Rico, interns work 24-hour shifts every 4–6 days alongside daytime clinical duties. These schedules help maintain hospital coverage but increase fatigue, cognitive stress, and burnout.

• The Accreditation Council for Graduate Medical Education sets duty-hour regulations to improve patient safety and physician well-being. ACGME guidelines include:

- Maximum of 80 work hours per week, maximum of 24 consecutive clinical hours (plus transition time), at least one day off per week.
- Current guidelines do not specify how schedules should be structured or workloads distributed.

• Traditional scheduling methods often create unequal distributions of overnight calls, weekend shifts, and consecutive workdays.

• Research shows sleep deprivation impairs:

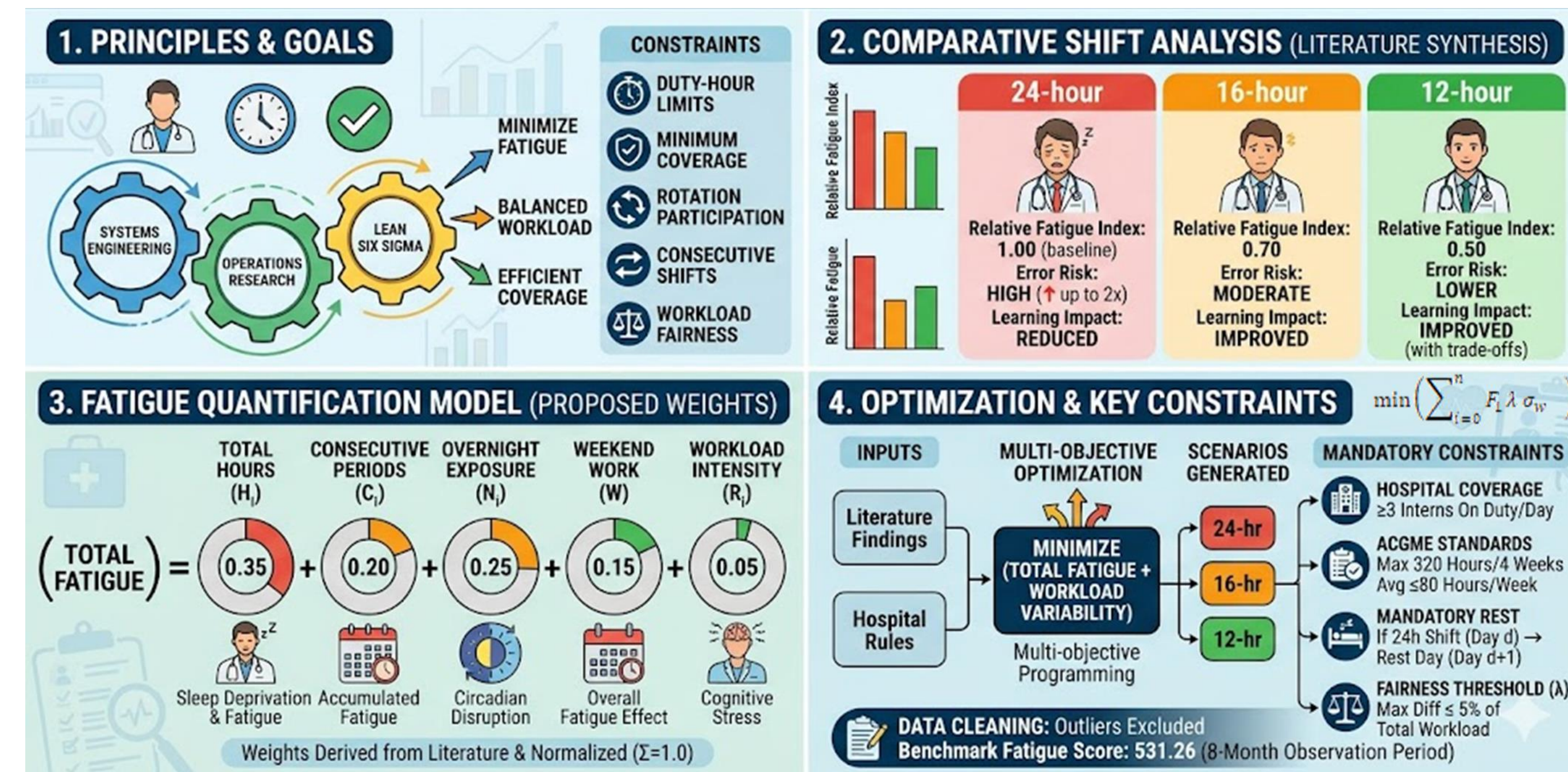
- Attention, Decision-making, Procedural skill acquisition

• This project aimed to develop a multi-objective optimization model for intern scheduling to:

- Reduce cumulative fatigue scores
- Reduce workload variability
- Maintain clinical coverage and ensure compliance with duty-hour regulations

The goal was to support data-driven scheduling strategies that improve physician well-being and educational outcomes.

Methodology



Results

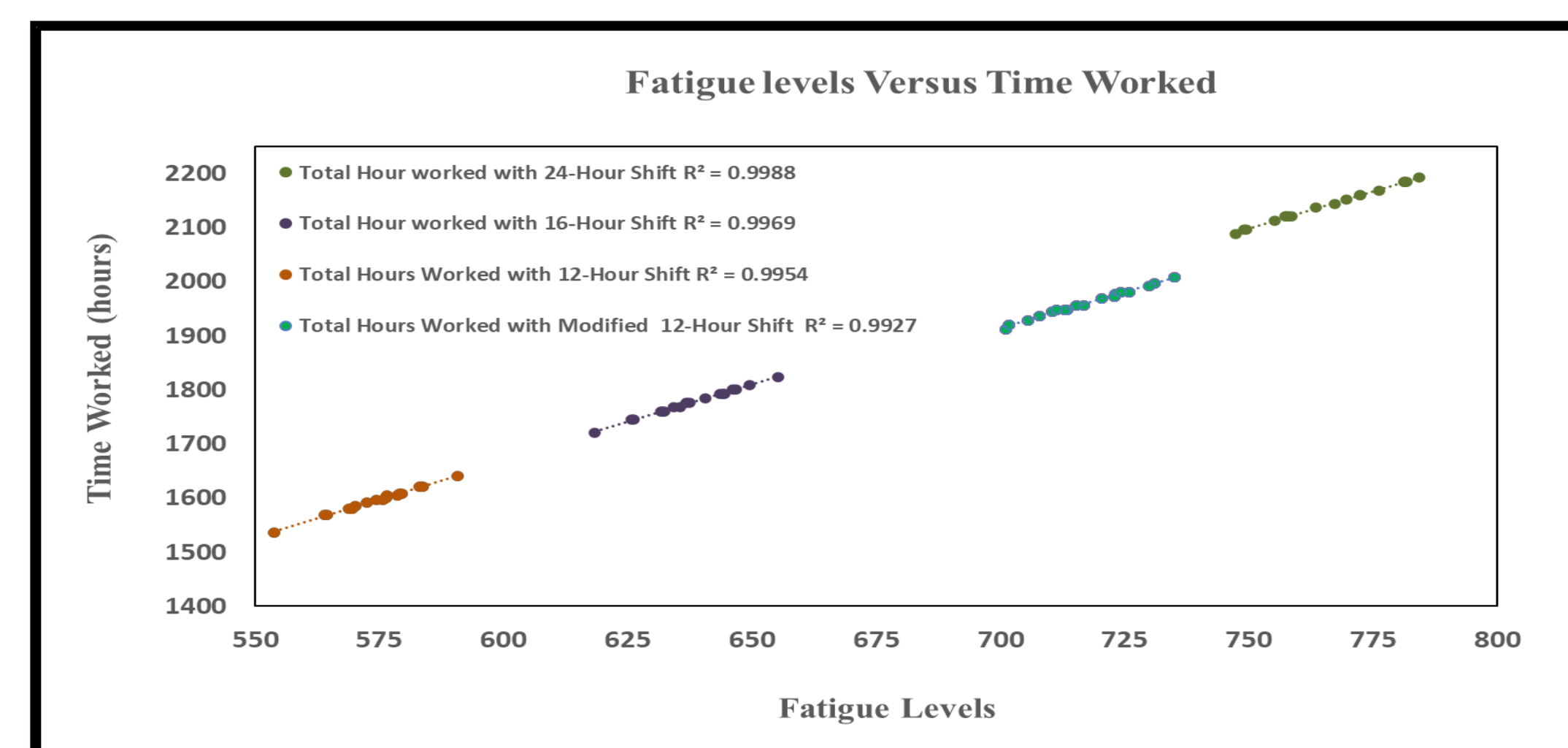


Figure 1. Fatigue levels versus time worked with 24-hour (red), 16-hour (blue), and 12-hour (orange), 12-hour modified (purple) duty calls.

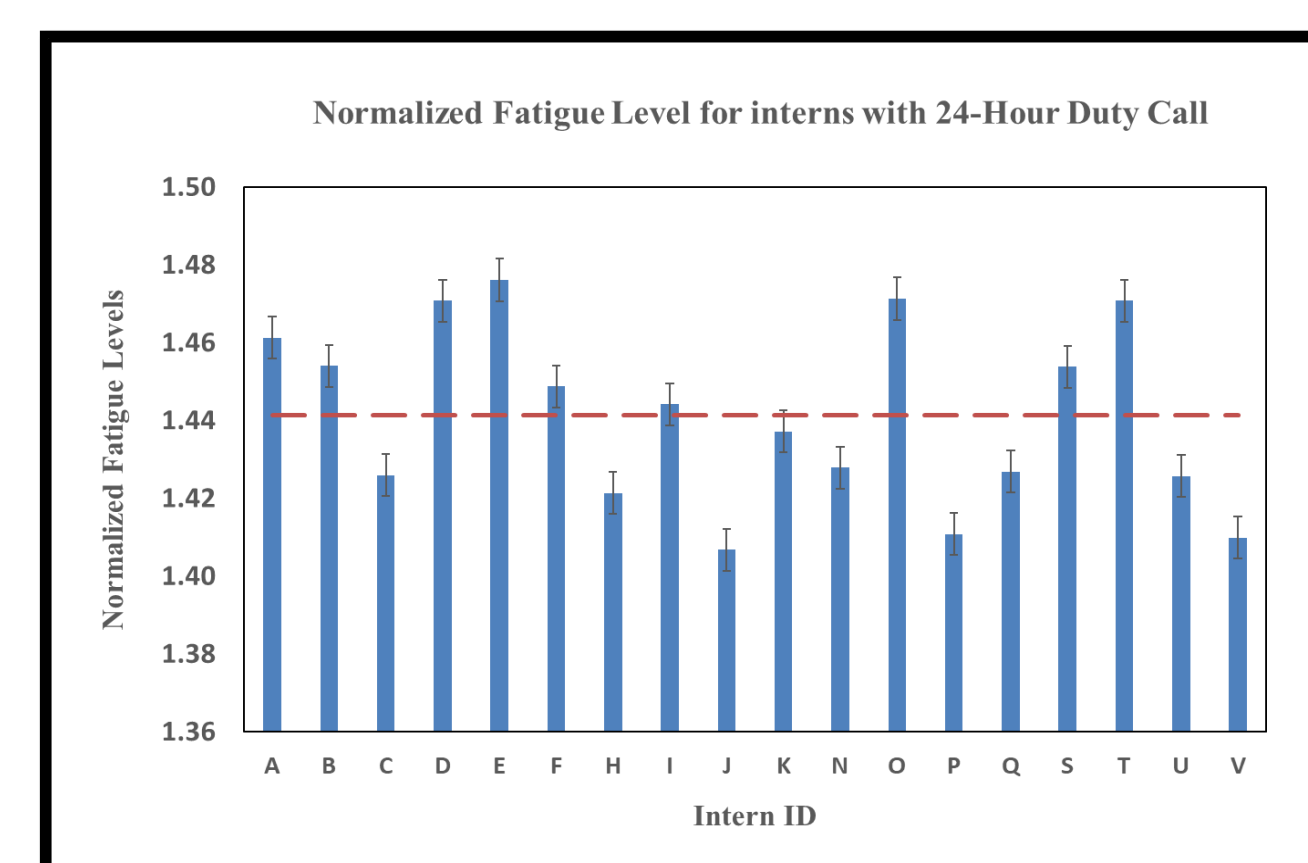


Figure 2. Normalized intern's fatigue level when completing a 24-hour shift.

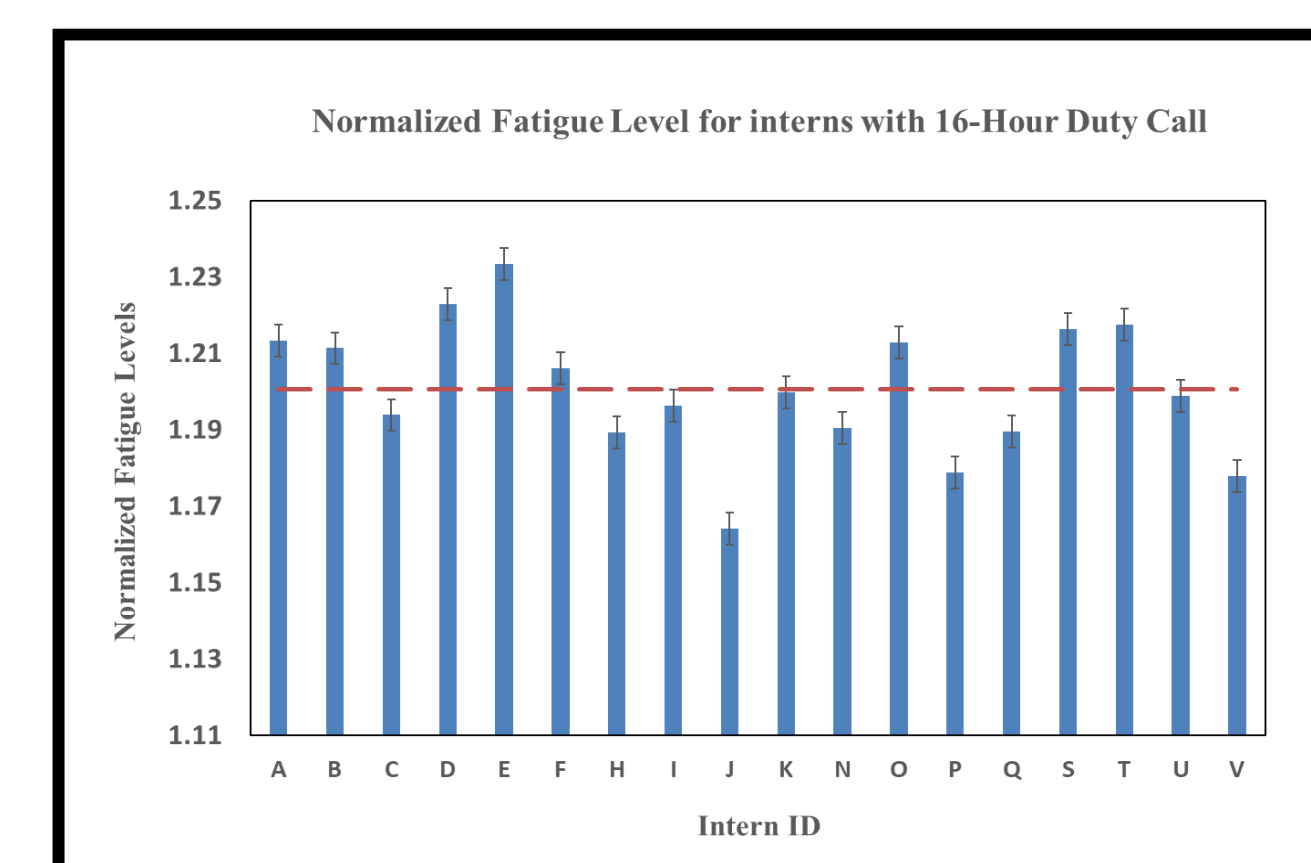


Figure 3. Normalized intern's fatigue level when completing a 16-hour shift.

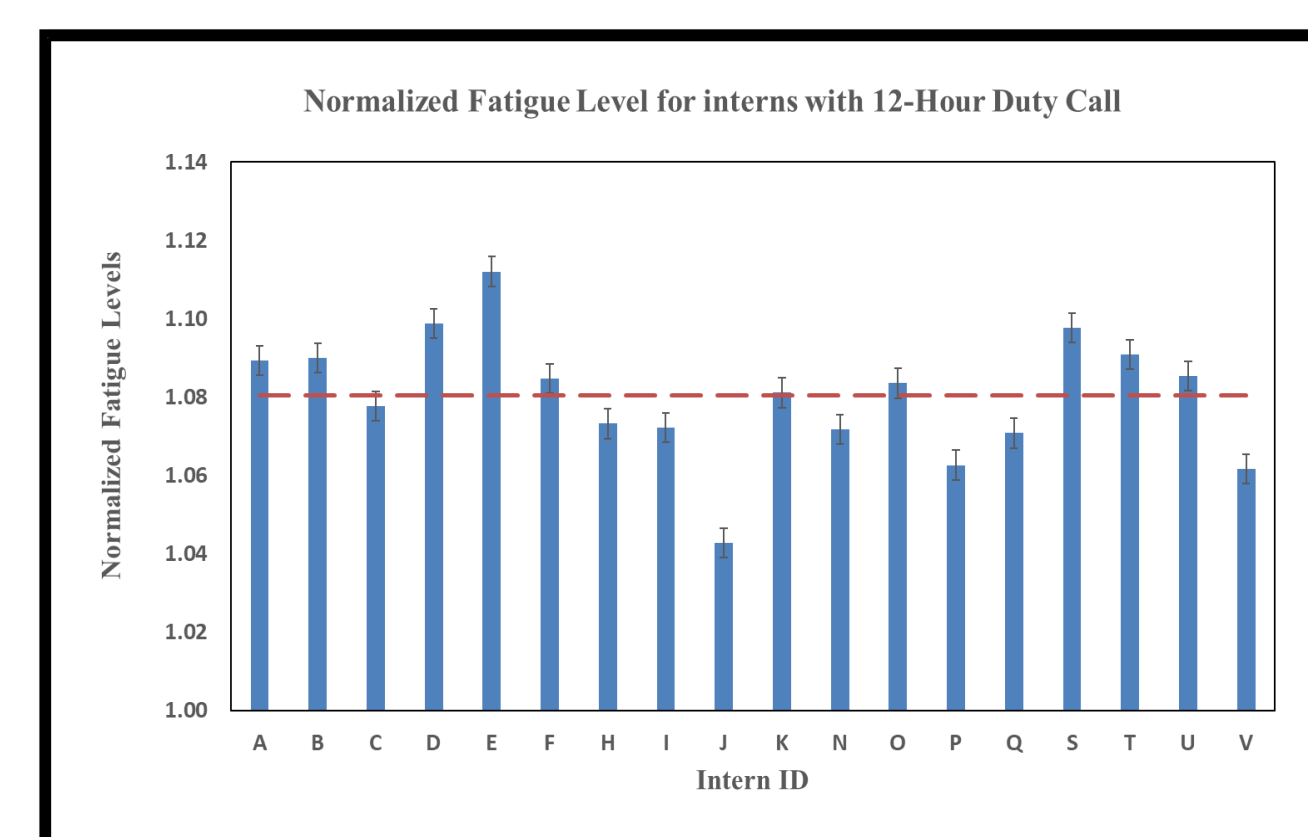


Figure 4. Normalized intern's fatigue level when completing a 12-hour shift.

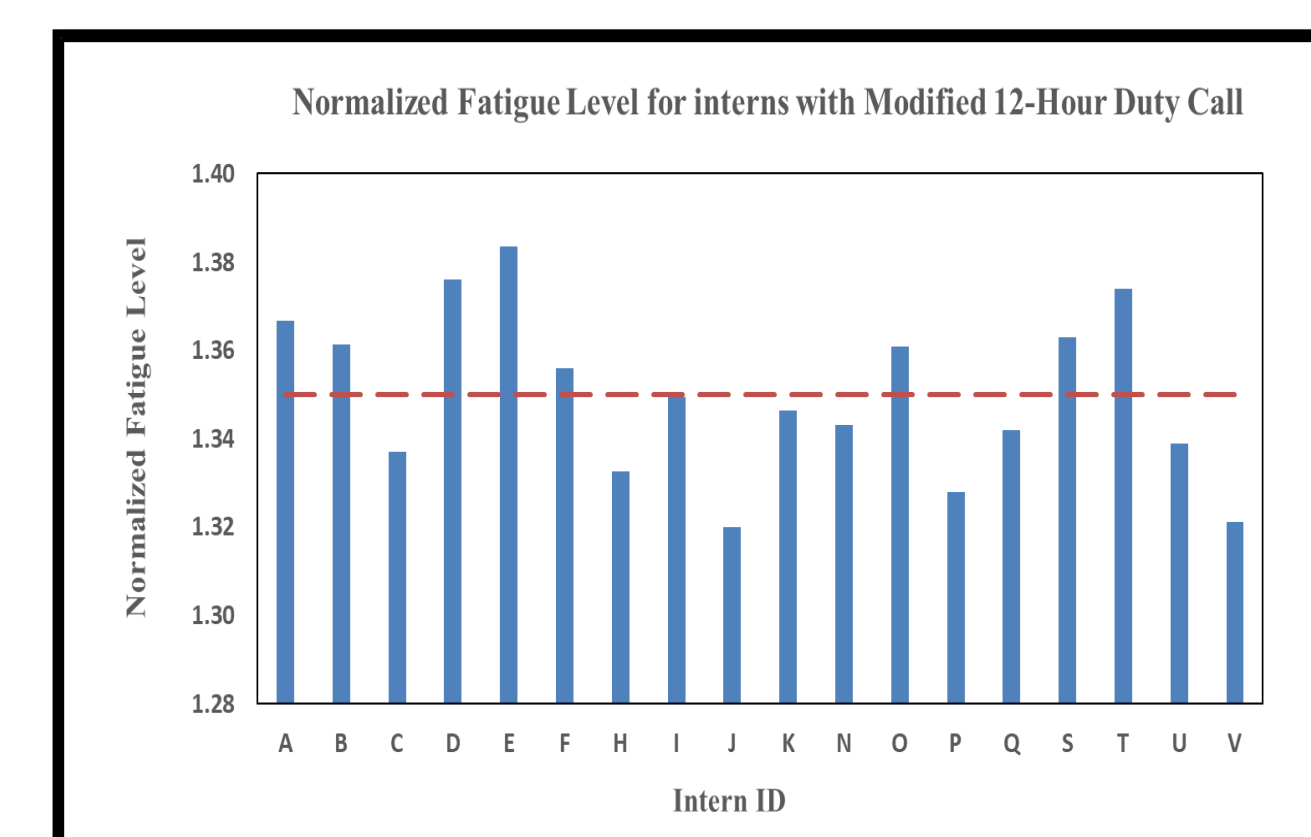
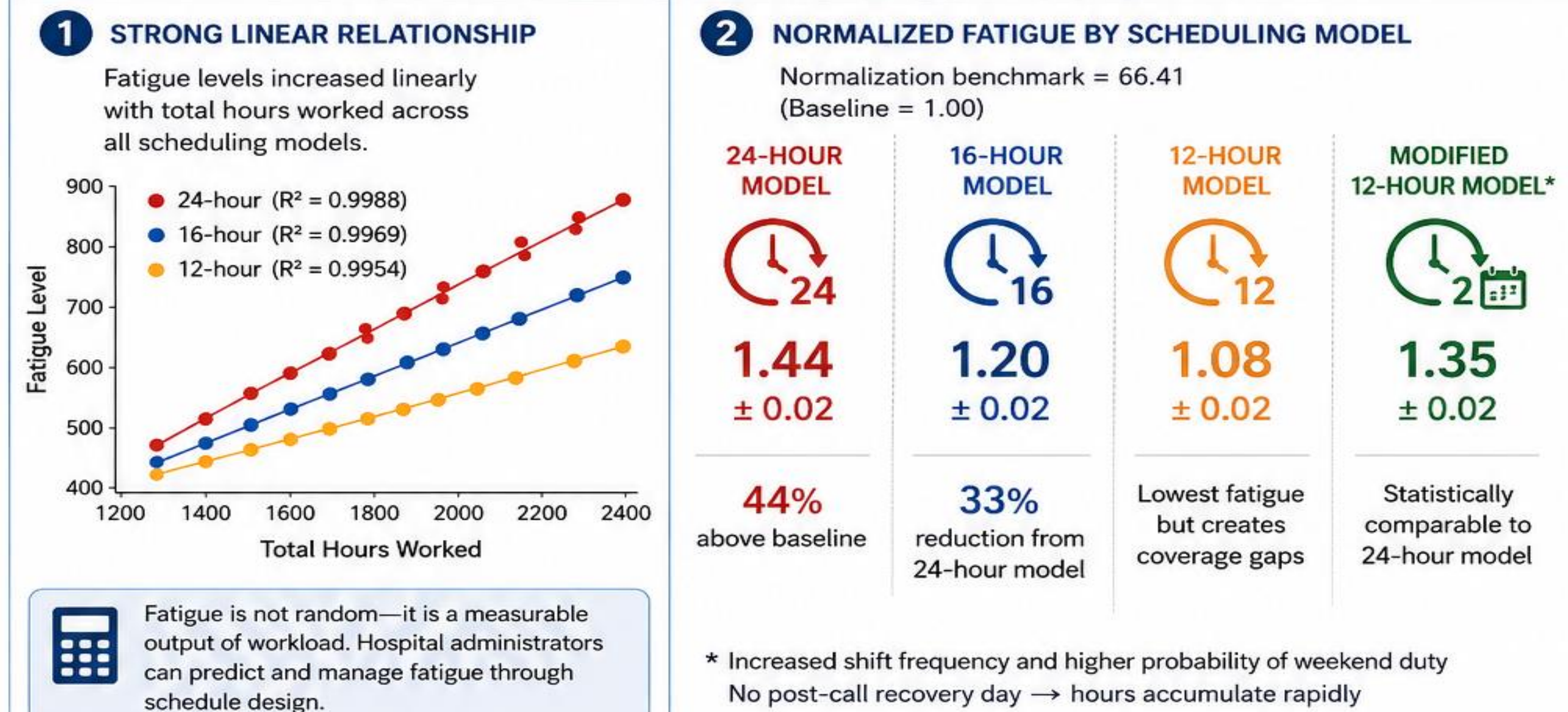


Figure 5. Normalized intern's fatigue level when completing a modified 12-hour shift.

Conclusion

INTERN FATIGUE IS STRONGLY LINKED TO HOURS WORKED

Statistical Analysis of Scheduling Models ($n = 18$)



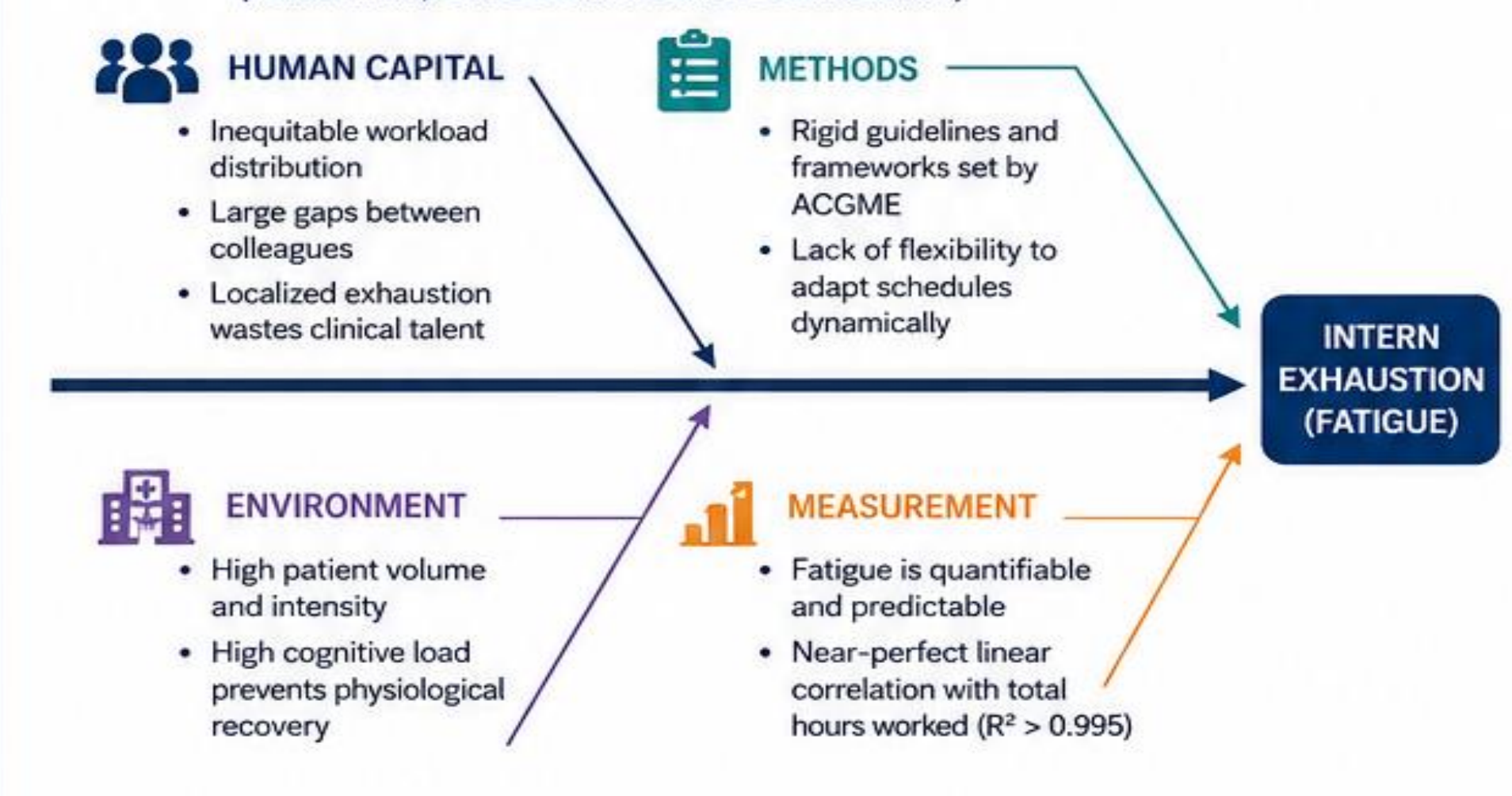
3 SUMMARY OF FATIGUE AND HOURS WORKED ACROSS MODELS

Scheduling Model	Fatigue Average (mean ± SE)	Normalized Average Fatigue (mean ± SE)	Average Total Hours Worked (mean ± SE)
24-hour	765.69 ± 12.23	1.44 ± 0.02	2140.89 ± 33.62
16-hour	637.87 ± 9.40	1.20 ± 0.02	1776.00 ± 25.89
12-hour	573.95 ± 8.50	1.08 ± 0.02	1593.55 ± 23.65
Modified 12-hour	717.19 ± 10.02	1.35 ± 0.02	1959.33 ± 26.68

4 KEY TAKEAWAYS

- Fatigue increases linearly with total hours worked ($R^2 > 0.995$ for all models).
- 16-hour shifts reduce fatigue compared to 24-hour shifts.
- 12-hour shifts minimize fatigue but compromise hospital coverage.
- Modified 12-hour shifts increase fatigue due to higher frequency and no recovery day.
- Fatigue is a systemic scheduling defect that can be predicted and addressed through data-driven design.

5 SYSTEMIC DRIVERS OF INTERN EXHAUSTION (ISHIKAWA / CAUSE-AND-EFFECT DIAGRAM)



Fatigue increases the probability of clinical errors, which represent defects in patient care and prevent interns from engaging in research or clinical learning. This simulation tool facilitates the rational design of schedules through proactive monthly fatigue monitoring. Such data-driven oversight allows for a reduction in average fatigue while enhancing patient safety and resident well-being.

The near-perfect correlation between work duration and fatigue suggests that intern burnout is a mathematically predictable outcome of system design rather than an individual failure. Adopting a sixteen-hour shift model aligns medical training with modern High Reliability Organization standards by minimizing the physiological drivers of error. Therefore, a transition to a sixteen-hour model is recommended to mitigate the risk of clinical defects, improve academic engagement, and optimize patient safety.

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