Heart-Rate–Based Work–Rest Scheduling in Construction

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Abstract—**Construction work is physically demanding and may lead to cumulative fatigue and increased injury risk. Wearable devices allow continuous monitoring of workers' physiological strain, but few studies translate such data into concrete work–rest decisions on active sites. This extended abstract summarizes an ongoing field study that uses wrist-based heart-rate monitoring to design and evaluate a physiology-guided work–rest framework for construction workers. Minute-level heart-rate data from 33 workers across three building sites were converted to Heart Rate Reserve (%HRR) and used to trigger candidate rest breaks and define a marginal recovery metric. Then, a Mixed-Integer Linear Programming (MILP) model selected breaks under a daily rest cap. Preliminary results show that targeted, physiology-informed breaks can substantially reduce exposure to high-strain minutes while remaining within realistic rest budgets.**

Keywords-wearable devices; construction workers; work–rest scheduling.

I. INTRODUCTION

Construction remains one of the most labor-intensive sectors, and project outcomes depend strongly on workers' health and productivity. In the United States, construction still accounts for about one-fifth of workplace fatalities [1], and cumulative fatigue is a key day-to-day contributor to this risk. A recent review highlights that fatigue in construction is linked to musculoskeletal disorders, performance errors, loss of motivation, and reduced productivity [2]. Beyond human costs, fatigue has been estimated to generate productivity losses on the order of $1,300–$3,100 per employee per year [3]. Experimental evidence also shows that fatigue degrades hazard recognition and risk perception, increasing the likelihood of accidents and near misses [4].

At the same time, modern sites are increasingly digitized, yet schedules and break policies rarely adapt to workers' physiological state. Wearable devices now offer a practical way to collect in-situ physiological data and support real-time safety monitoring [5]. The value of these data, however, lies in converting measurements into timely recovery opportunities. Recent construction studies have begun using wearable information to inform work–rest allocation and micro-breaks [6], but existing frameworks typically rely on simplified or simulated scenarios and do not fully exploit continuously collected, on-site physiology.

This study addresses that gap by using wrist-based Heart Rate (HR) monitoring on active construction sites to trigger and size breaks based on percentage heart-rate reserve and to allocate them through an optimization model that prioritizes breaks with the greatest marginal physiological recovery. **Figure 1** illustrates the system architecture of the proposed physiology-guided work–rest scheduling framework.

Figure 1. System architecture of the proposed physiology-guided work–rest scheduling framework.

The remainder of this paper is organized as follows. Section II describes the wearable monitoring setup and the proposed scheduling framework. Section III presents the optimization approach and preliminary results. Section IV addresses the discussion and ongoing work and concludes with final remarks.

II. METHODS: WEARABLE MONITORING AND SCHEDULING FRAMEWORK

A. Field Data Collection

Data were collected from 33 male construction workers across three active building sites in Beirut, Lebanon, covering residential and institutional projects with typical concrete and finishing trades. Workers wore a Fitbit Inspire 3 device on their wrist throughout their time on site over multiple weeks, and their heart rate was continuously recorded during working hours. For each worker, resting and age-predicted maximal heart rates were used to compute Heart Rate Reserve (HRR), and minute-level workload was expressed as %HRR [7], [8] using:

$$\%HRR = \frac{HR_{Work} - HR_{Resting}}{HR_{Maximum} - HR_{Resting}} \times 100\% \qquad (1)$$

Building on this, a rest-allowance (RA) formulation that converts time spent at elevated %HRR into required rest is used. Conceptually, a break is modeled as a period during which heart rate decreases from the pre-break level toward resting heart rate; as HR is assumed to relax toward rest over the break, each break minute "pays back" some of the accumulated physiological load. The rest allowance thus specifies how many break minutes are needed, given a

worker's recent %HRR profile, to bring exposure back toward a target strain level.

B. Identifying Candidate Breaks

For each worker-day, RA was evaluated on a 60-minute sliding window. Whenever RA is greater than 0, a candidate break was created with a duration equal to the RA output, then rounded to 5-minute increments. During each simulated break, %HRR was modeled to drop toward resting levels, and its benefit was summarized as Δ%HRR, defined as the average difference between the no-break and with-break %HRR over the break and its immediate recovery period.

C. Optimization of Break Selection

As it is not practical to allocate unlimited rest, we imposed a daily cap on non-lunch breaks (e.g., 30 minutes per worker per day). A Mixed-Integer Linear Programming (MILP) model then selects a subset and duration of candidate breaks subject to:

- the daily rest budget per worker,
- separation between breaks (minimum spacing), and
- alignment with the actual working window.

Break benefit is quantified using a marginal recovery metric, Δ%HRR. The MILP objective is to maximize the minute-weighted sum of Δ%HRR over all selected breaks, effectively prioritizing breaks that yield the greatest physiological relief per minute of rest.

III. Results: Impact on Physiological Strain

Across the three sites, the mean age was 29 years. At the individual level, worker mean %HRR ranged from about 17% to 41%, with most standard deviations <5% HRR, indicating modest within-worker variability but substantial differences between workers. Approximately 92% of worker-days triggered at least one candidate break, with the modal required rest lying between 5 and 15 minutes per day and an average of about 40 minutes of rest per worker-day when no cap was imposed. Under a 30-minute daily limit, the MILP retained roughly 80–85% of the total candidate rest time by shortening rather than discarding many breaks. This produced optimized break schedules that were more clustered and better aligned with sustained high-strain periods.

As per **Figure 2**, applying the optimized breaks reduced the share of workday minutes spent at or above 40% HRR while keeping the whole-day mean %HRR nearly unchanged, indicating that recovery was concentrated in high-strain windows rather than simply lowering overall workload.
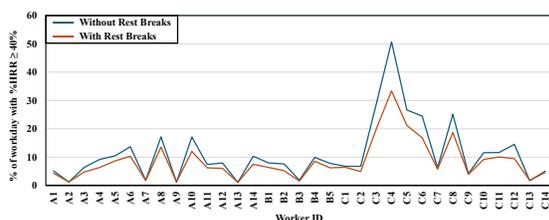

Figure 2. Share of workday minutes with %HRR ≥40% before vs. after MILP breaks.

At the worker level, most workers experienced a reduction in minute-weighted %HRR in the break windows compared with the corresponding no-break trajectories. These results suggest that relatively small amounts of targeted rest, informed by wearable data and simple optimization, can meaningfully reshape the distribution of physiological strain across the workday.

IV. Discussion and Ongoing Work

The findings demonstrate that minute-level wrist-based heart-rate data from active construction sites can be transformed into actionable, physiology-guided work–rest schedules. By converting %HRR time series into rest-allowance–based candidate breaks and then selecting a feasible subset via an optimization model that maximizes marginal recovery under a daily rest cap, the framework provides a concrete path toward data-driven rest policies that reduce high-strain exposure without imposing excessive downtime. Among the limitations of the study are that the current implementation relies on a single physiological signal (heart rate) and site-specific data from three projects in one city. Future work should expand the dataset, explore richer sensing (environmental and activity measures), incorporate subjective recovery indicators, refine the recovery model, and test on-site implementation of the optimized schedules.

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