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Abstract

Circadian rhythmicity and Risk Index validation in railway traffic control

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Problem

This paper describes the findings of a data-driven fatigue research project at Belgian railway traffic control. First, we estimate the circadian rhythmicity in registered human errors. Second, we statistically evaluate the validity of the Risk Index tool (Spencer et al., 2006) through a multivariate Tobit regression analysis of its impact on these human errors. The regression model also considers factors not taken into account by the Risk Index methodology. As such, we extend and complement previous research on the validity of the Risk Index by Greubel et al. (2010) and Greubel and Nachreiner (2013).

Method

In order to estimate the circadian rhythm in hourly error occurrence, and following Folkard et al. (2006), we perform several cosinor regressions on human errors in railway traffic control. Error occurrence is corrected for exposure by taking into account traffic volumes.

Next, a multivariate Tobit model empirically examines the relationship between the exposure-corrected human errors and the Spencer et al. (2006) Risk Index scores. By applying a Tobit regression, we account for zero values in error occurrence. The regression model additionally considers variables capturing industry-specific settings, age, gender, part-time work and day-of-week (i.e., factors which are not taken into account by the Risk Index methodology).

In close cooperation with railway experts from Infrabel, the state-owned company running the Belgian railway infrastructure, we analyze real-life data from 11 computerized Traffic Control Centers. We retrospectively analyze a unique full year dataset, containing more than 11,000 work shifts. The signalling and dispatching work in the Traffic Control Centers is standardized through non-overlapping 8-hour work shifts, starting at 06:00, 14:00 and 22:00 (i.e., early, late, and night shift). However, local management has the authority to organize and adapt work shift patterns in functions of their needs (e.g. team composition, direction and speed of shift rotation, distribution of rest days). Work schedule risk is assessed for each individual traffic controller with actual staff schedules. We complement the obtained Risk Index scores with intra-company data (e.g. traffic volumes, traffic controller age and gender). The dataset is further enriched with the human errors detected by the traffic control system (relatively frequent but non–critical task errors, such as erroneous ordering of signal commands). The human errors are not identified at individual level, but at team level (i.e., the group of traffic controllers present in the control center during the work shift). For the purpose of the Tobit regression, data is further aggregated by each 8-hour work shift. Data is collected, verified, and validated by a custom-developed Business Intelligence tool.

Results

The cosinor parameter estimates are all statistically significant, with an acrophase estimate (circadian peak) around 2 am. This estimate proves robust to alternative data aggregations (e.g. with errors calculated per shift instead of per hour, see Folkard et al., 2006).

The multivariate Tobit regression reveals a positive and highly significant effect of the average team Risk Index on human error occurrence. Control variables reflecting operational conditions (such as the percentage of automatically commanded signals) are also significant. There is no significant impact of average team age, gender (percentage of male traffic controllers) or part-time work (percentage in the team). Finally, day-of-week dummy variables exhibit varying parameter signs and significance levels. Tobit marginal effects indicate that, all other things being equal, the probability of making at least one error is highest on Saturdays (+ 6% compared to Mondays), and lowest on Tuesdays, Wednesdays and Thursdays. Regression results are robust to changes in model specification.

Discussion

The estimated 24-hour rhythm, exhibiting an acrophase at 02:00 hours, is closely aligned with previous research examining circadian employee performance (Folkard and Tucker, 2003, circadian low at 03:00) or the risk for accidents and injuries (Folkard et al., 2006, acrophase around midnight).

Our Tobit regression result validates the Risk Index in a real-life setting, and therefore extends previous web survey - based research on the validity of the Risk Index by Greubel et al. (2010) and Greubel and Nachreiner (2013). Moreover, following a suggestion by Greubel and Nachreiner (2013), we analyzed a potential 'day-of-week' effect and found a significant impact on the exposure-corrected error levels.

Also, in line with the recommendation by Dawson et al. (in press) to apply biomathematical models in a 'post-implementation surveillance mode', our custom-developed Business

Intelligence tool allows for a further (non-statistical but operationally intuitive) probing of the data by railway experts.

Summary

The present study is part of an ongoing fatigue risk research project, performed in close collaboration with the Belgian railway infrastructure company Infrabel. Applying cosinor rhythmometry and Tobit regressions, our analysis not only estimates circadian rhythmicity in human error, but also validates the Risk Index Spencer et al. (2006) under real-world circumstances. As suggested by our regression results, an enhancement of the Risk Index to account for 'day-of-week' effects could further reinforce the accuracy of the tool. Finally, our research also aims to bridge the gap between theory and practice, by deploying a Business Intelligence tool for ex-post Risk Index analysis.

References

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