DOI: 10.62897/COS2025.3-1.91

10-12, November 2025, Győr

INTEGRATING OBJECTIVE AND SUBJECTIVE WORKLOAD ASSESSMENT IN ERGONOMIC JOB ROTATION DESIGN: A CONCEPTUAL FRAMEWORK

Tilen Medved*, Zvone Balantič
*University of Maribor, Faculty of Organizational Sciences, Kidričeva 55A, Kranj, Slovenia
tilen.medved2@um.si

Job rotation is widely used to reduce physical workload, but rotation plans often fail when they consider only objective exposure or only perceived workload. Effective rotation design requires a consistent representation of workload that combines both physical and subjective aspects of work. This paper presents a conceptual framework for the design of ergonomic job rotation based on the integration of objective and subjective workload assessment. Objective workload is obtained using wearable inertial sensors and evaluated with the Ovako Working Posture Analysing System (OWAS), while subjective workload is assessed using the NASA Task Load Index (NASA-TLX). The main contribution of the paper is a structured research framework that defines the planned experimental procedure for developing and validating a job rotation model. The framework includes workload measurement, integration of indicators, design of rotation scenarios, simulation of alternative schedules, and experimental validation in a controlled environment. The paper does not present empirical results, but outlines the methodological basis for later simulation and optimization of rotation schedules. The proposed approach aims to support more transparent and data-based job rotation design and to improve workload balance between workers.

1. Introduction

Workload management matters because imbalance and overload can harm outcomes for both people and organizations. A large empirical study linked perceived workload balance to job satisfaction, using a clear workload-balance mechanism in organizations (Inegbedion et al., 2020).

Ergonomic job rotation aims to reduce musculoskeletal risk by limiting long exposure to high-demand tasks and by increasing exposure variation. Yet reviews argue that the benefit of "more variation" has weak long-term evidence unless the rotation design truly changes exposure patterns and supports recovery (Mathiassen, 2006).

Operations research and industrial engineering studies show that rotation design is a constrained scheduling and assignment problem. Algorithms can reduce ergonomic risk, but results depend heavily on how the model defines risk and workload (Otto and Battaïa, 2017).

A core practical problem persists: many workplaces gather either objective exposure data (postures, joint angles) or subjective feedback (fatigue, demand), then act on each stream separately. NASA-TLX offers a standard multidimensional approach and supports both paper and app-based use (Hart and Staveland, 1988). OWAS offers a practical observational method for evaluating working postures after short training, and many digital human simulation platforms implement OWAS-based reports (Wahyudi et al., 2015).
This paper addresses one narrow, publishable research unit within a broader PhD: the integration of objective and subjective workload assessment for job rotation design. The central goal is not to claim an optimal rotation plan now, but to define a defensible workload representation that can later become an input to optimization.

2. Literature review

Job rotation design research sits at the intersection of ergonomics, occupational health, and scheduling.
Evidence and cautions on rotation outcomes: A systematic review in manufacturing asked how job rotation impacts musculoskeletal disorders and psychosocial factors, highlighting the need to design rotation rather than assume benefits (Padula et al., 2017). A meta-analysis on job and task rotation found positive relations with job satisfaction and other outcomes, but also concluded that many expectations of rotation do not fully hold across studies (Mlekus and Maier, 2021). A biomechanics-focused review argued that rotation outcomes depend strongly on the composition of the job pool - if high-risk tasks remain, job redesign may matter more than rotation alone (Mehdizadeh et al., 2020).
Biomechanical exposure variation requires concepts and metrics. Evidence for "variation helps" is limited unless variation changes exposure distributions over time (Mathiassen, 2006). This supports a measurement-driven approach that treats workload as time-based exposure, not only as a single static score.
Classical approaches integrated safety criteria into scheduling via integer programming and genetic algorithms, showing the feasibility of algorithmic job rotation under ergonomic constraints (Carnahan et al., 2000). A survey of line planning and job rotation scheduling emphasized that established ergonomic risk estimation methods can be integrated into operational planning models, shifting ergonomics from post-hoc checks to planning-stage decisions (Otto and Battaïa, 2017).
Modern rotation algorithms explicitly embed ergonomics, competence, and organizational constraints. A multi-criteria genetic algorithm approach designed rotation schedules while considering worker-job adequacy and competence, linking ergonomics with assignment quality and satisfaction (Asensio-Cuesta et al., 2012a). A genetic algorithm approach used OCRA-based risk evaluation to design schedules in repetitive work (Asensio-Cuesta et al., 2012b). Game-theory scheduling methods incorporated worker preferences and competence and produced feasible schedules fast in case studies (Asensio-Cuesta et al., 2019).
IMUs have become common in occupational kinematic assessment, with clear benefits (mobility, field use) and known challenges (magnetic disturbance, drift, placement) (Schall et al., 2022). A 2024 systematic review analyzed how inertial sensors can affect users in ergonomic assessment, pointing to transparency and acceptability issues (García-Luna et al., 2024). Industry-facing reviews of wearables report adoption barriers such as comfort, scalability, and privacy, even when accuracy improves (Alenjareghi et al., 2026). Empirical IMU systems for WMSD risk assessment continue to emerge in manufacturing settings (Baklouti et al., 2024).
Regarding subjective workloads, NASA-TLX development work established a multidimensional subjective workload scale, and later meta-analytic work provided reference values and patterns across domains, supporting benchmarked interpretation (Hart and Staveland, 1988).

Prior workload research integrated subjective scales with objective or physiological signals using multivariate approaches such as PCA to form combined indices (Miyake, 2001). Recent work continues to support multimodal workload assessment rather than single-metric reliance (Dhengre and Rothrock, 2024).
Overall, literature supports (1) the need for careful workload modeling, (2) the feasibility of algorithmic rotation scheduling, and (3) the growing role of wearables and subjective tools. It also exposes a gap: fewer frameworks specify how to fuse objective postural exposure and subjective workload in a way that remains transparent, robust, and usable for later scheduling optimization.

3. Conceptual research framework for ergonomic job rotation design

The purpose of the proposed research is to develop and validate an ergonomic job rotation model based on the integration of objective and subjective workload assessment. Since the doctoral research is still in the conceptual stage, the present paper does not introduce a finalized optimization model, but instead proposes a structured experimental framework that defines the planned research procedure. The framework describes the sequence of steps required to collect workload data, integrate different types of measurements, design alternative job rotation schedules, and evaluate their effects on employee workload and workload distribution.
The framework is based on the assumption that effective job rotation design requires a combination of ergonomic measurement, worker perception, and systematic evaluation of different rotation scenarios. Previous studies have shown that job rotation can reduce ergonomic risk only when workload is properly assessed and when rotation schedules are designed using consistent criteria (Otto and Battaïa, 2017). In addition, biomechanical exposure varies over time and cannot be adequately described using a single indicator, which makes it necessary to consider multiple sources of information when evaluating work tasks (Mathiassen, 2006). For this reason, the proposed framework combines objective ergonomic assessment with subjective workload evaluation.

3.1 General structure of the framework

The conceptual framework consists of several consecutive phases, starting with the definition of the experimental environment and ending with the evaluation of alternative job rotation schedules. Each phase produces information that is used as input for the next phase. The framework is designed to allow gradual development of the rotation model and to enable later extension with optimization methods if needed.

The main phases of the framework are:

1. Definition of the experimental system
2. Objective workload assessment
3. Subjective workload assessment
4. Integration of workload indicators
5. Design of rotation scenarios
6. Simulation and comparison of scenarios
7. Experimental validation
8. Evaluation of workload balance and fairness
9. Formulation of guidelines for practical application

This structure follows the logic of ergonomic system design, where measurement, analysis, and evaluation are performed before changes to the work organization are introduced (Karwowski, 2005).

3.2 Definition of the experimental system

The first phase of the framework is the definition of the experimental environment in which the job rotation model will be developed. The research is planned to be conducted in a controlled laboratory setting and later extended to an industrial environment. The experimental system should include several workers and several workplaces that differ in physical and cognitive demands. Each worker must be trained to perform all selected tasks in order to allow different rotation combinations.
The number of workers and workplaces is not fixed in advance, but the proposed design assumes a small group that allows detailed measurement and comparison of different rotation schedules. Similar experimental approaches have been used in previous studies on job rotation scheduling and ergonomic risk reduction (Carnahan et al., 2000).

3.3 Objective workload assessment

In the second phase, objective workload data are collected for each worker–task combination. The proposed research uses inertial motion sensors to record body movements during work tasks. Sensor data allow the reconstruction of body posture and joint angles, which can then be evaluated using ergonomic assessment methods such as OWAS.
Wearable inertial sensors are increasingly used in ergonomic research because they provide objective information about posture and movement in real working conditions (Schall et al., 2022). Automated or semi-automated evaluation of posture makes it possible to analyse a larger number of tasks than with purely observational methods. The result of this phase is an objective description of the physical workload associated with each task.

3.4 Subjective workload assessment

Objective measurements alone do not fully describe the demands of work, because workers may experience the same task differently depending on fatigue, experience, or cognitive load. For this reason, the framework includes subjective workload assessment as a separate phase.
Subjective workload will be measured using the NASA-TLX questionnaire, which is widely used for the evaluation of perceived workload in both physical and cognitive tasks (Hart and Staveland, 1988). The questionnaire provides an overall workload score as well as information about different components of workload, such as mental demand, physical demand, and effort.
Previous research has shown that subjective workload indicators are important when evaluating work systems, because they reflect the worker's perception of difficulty and strain (Hertzum, 2021). The result of this phase is a subjective workload profile for each worker–task combination.

3.5 Integration of workload indicators

After objective and subjective data have been collected, the next step is to combine both sources of information into a unified workload description. The aim of this phase is not to define a final mathematical model, but to establish a procedure that allows comparison of different tasks and workers using consistent criteria.

The integration of workload indicators makes it possible to evaluate tasks from several perspectives at the same time and to avoid decisions based on only one type of measurement. This approach is consistent with ergonomic principles that require consideration of both physical and cognitive demands when designing work systems (Karwowski, 2005). The combined workload description will later serve as the basis for designing and comparing job rotation schedules.

3.6 Design of rotation scenarios

In the next phase, different job rotation scenarios are defined. A scenario specifies the order in which workers perform tasks and the duration of each task. Several alternative schedules will be created, including:

- The current work organization without rotation
- Simple fixed rotation
- Randomly assigned rotation
- Rotation based on workload assessment.

The purpose of this phase is to create comparable alternatives that can be evaluated using the same workload data. Previous studies have shown that the effect of job rotation depends strongly on how the schedule is designed, and that poorly designed rotation may not reduce ergonomic risk (Mehdizadeh et al., 2020).

3.7 Simulation and comparison of scenarios

Before testing rotation schedules in practice, the framework proposes the use of simulation. Simulation allows the evaluation of different scenarios without exposing workers to unnecessary risk. Each scenario can be analysed in terms of total workload, distribution of workload between workers, and variability of exposure over time.

Optimization methods may be introduced at this stage in later phases of the doctoral research, but they are not required for the conceptual framework presented in this paper. The main objective is to establish a systematic procedure for comparing rotation schedules.

3.8 Experimental validation

After simulation, selected rotation schedules will be tested in a controlled experiment. Workers will perform tasks according to the chosen schedule, and the same objective and subjective measurements will be repeated. This allows direct comparison between the original work organization and the proposed rotation model. Experimental validation is necessary because theoretical or simulated improvements do not always lead to real reduction of workload in practice (Otto and Battaïa, 2017).

3.9 Evaluation of workload balance and fairness

In addition to total workload, the framework considers the distribution of workload between workers. A rotation schedule should not only reduce average workload, but also prevent large differences between individuals. Perceived imbalance in workload may reduce job satisfaction and acceptance of organizational changes (Inegbedion et al., 2020). Therefore, the evaluation will include indicators of workload balance, such as differences between workers and changes over time.

3.10 Application of the framework

The final phase of the framework is the formulation of guidelines for practical use. Based on the results of the experiment, the research aims to define a procedure that can be applied in real industrial systems. The long-term goal of the doctoral research is to support the design of job rotation systems that reduce workload, improve fairness, and allow systematic ergonomic evaluation using modern measurement technologies. The framework presented in this paper represents the first step toward that goal and provides the methodological basis for the subsequent stages of the doctoral research.

4. Proposed methodology

The proposed methodology defines the planned experimental procedure for the development and validation of an ergonomic job rotation model based on the integration of objective and subjective workload assessment. Since the doctoral research is still in the conceptual stage, this section describes the research design and planned analyses rather than final results.
The experiment will be carried out in a controlled laboratory environment and later extended to an industrial setting. The experimental system will consist of several workers and several workplaces with different physical and cognitive demands. Each participant will be trained to perform all selected tasks in order to allow the creation of different job rotation schedules. A similar approach has been used in previous research on job rotation and ergonomic risk reduction (Carnahan et al., 2000).

Objective workload will be measured using inertial motion sensors that record body movements during work tasks. Sensor data will be used to evaluate working postures using an ergonomic assessment method such as OWAS. Wearable sensors enable objective measurement of movement in real working conditions and allow the analysis of a larger number of tasks than traditional observational methods (Schall et al., 2022).
Subjective workload will be assessed using the NASA-TLX questionnaire after the performance of each task or task sequence. This method is widely used for the evaluation of perceived workload and provides information about both physical and mental demands (Hart and Staveland, 1988).
After objective and subjective measurements have been collected, both sources of information will be combined into a unified workload description for each worker–task combination. The purpose of this step is to allow comparison of tasks using consistent criteria and to support the design of job rotation schedules. The exact method of integration will be defined during the research, while the present study focuses on the overall procedure rather than on a final mathematical model.
Based on the collected data, several job rotation schedules will be created, including work without rotation, simple fixed rotation, and rotation based on workload assessment. These schedules will be compared using simulation and experimental testing. The evaluation will consider total workload, changes in workload over time, and the distribution of workload between workers.

The final stage of the experiment will include testing of selected rotation schedules in a controlled environment. Objective and subjective workload measurements will be repeated in order to compare the original work organization with the proposed rotation model. In addition to total workload, the analysis will consider the balance of workload between workers, since perceived imbalance may affect job satisfaction and acceptance of organizational changes (Inegbedion et al., 2020).

All participants will provide informed consent before the experiment. If the research is later conducted in an industrial environment, approval from the appropriate ethics committee will be obtained before the experimental phase.

5. Conclusion

This paper presents a conceptual framework for the design of an ergonomic job rotation model based on the integration of objective and subjective workload assessment. The proposed approach combines motion capture data, ergonomic posture evaluation, and perceived workload measurement in order to provide a more comprehensive description of work demands. The framework defines a step-by-step procedure that includes workload measurement, integration of indicators, design of rotation schedules, simulation of different scenarios, and experimental validation.

The main expected contribution of the research is the development of a systematic procedure for designing job rotation schedules that considers both physical and cognitive workload. Unlike traditional approaches that rely only on observational assessment or simple rotation rules, the proposed framework aims to support data-based decision making and to improve the balance of workload between workers. Such an approach may contribute to the reduction of work-related musculoskeletal risk, improvement of perceived workload balance, and better acceptance of organizational changes.

The study also aims to provide a practical framework that can be applied in real industrial environments. The use of wearable sensors and standardized questionnaires makes it possible to analyse work tasks in a repeatable and transparent way. In the later stages of the doctoral research, the framework may be extended with simulation and optimization methods in order to support the design of rotation schedules in more complex production systems.

Several limitations must be considered. The present study describes the research design, and experimental results are not yet available. The number of participants and tasks in the first experiment will be limited, which may reduce the generalizability of the results. In addition, workload assessment is based on selected ergonomic indicators and does not include all possible factors that influence worker performance, such as environmental conditions or long-term fatigue.

Future work will focus on the implementation of the planned experiment, validation of the proposed framework, and testing of different job rotation schedules in both laboratory and industrial environments. The long-term goal of the research is to develop a validated ergonomic job rotation model that can be used to support the design of balanced and sustainable work systems.

References

- Alenjareghi M.J., Sekkay F., Dadouchi C., Keivanpour S., 2026, Wearable sensors in Industry 4.0: Preventing work-related musculoskeletal disorders. Sensors International, 7, 100343.
- Asensio-Cuesta S., Diego-Mas J.A., Canós-Darós L., Andrés-Romano C., 2012a, A genetic algorithm for the design of job rotation schedules considering ergonomic and competence criteria. International Journal of Advanced Manufacturing Technology, 60, 1161–1174.
- Asensio-Cuesta S., Diego-Mas J.A., Cremades-Oliver L.V., González-Cruz M.C., 2012b, A method to design job rotation schedules to prevent work-related musculoskeletal disorders in repetitive work. International Journal of Production Research, 50(24), 7467–7478.
- Asensio-Cuesta S., García-Gómez J.M., Poza-Luján J.-L., Conejero J.A., 2019, A game-theory method to design job rotation schedules to prevent musculoskeletal disorders based on workers' preferences and competencies. International Journal of Environmental Research and Public Health, 16(23), 4666.
- Baklouti S., Chaker A., Rezgui T., Sahbani A., Bennour S., Laribi M.A., 2024, A novel IMU-based system for work-related musculoskeletal disorders risk assessment. Sensors, 24(11), 3419, DOI: 10.3390/s24113419.
- Carnahan B.J., Redfern M.S., Norman B., 2000, Designing safe job rotation schedules using optimization and heuristic search. Ergonomics, 43(4), 543–560, DOI: 10.1080/001401300184404.
- Dhengre S., Rothrock L., 2025, Investigating mental workload across task modalities: a multimodal analysis using pupillometry. Ergonomics, 68(9), 1458–1471, DOI: 10.1080/00140139.2024.2414203.
- García-Luna M.A., Ruiz-Fernández D., Tortosa-Martínez J., Manchado C., García-Jaén M., Cortell-Tormo J.M., 2024, Transparency as a means to analyse the impact of inertial sensors on users during the occupational ergonomic assessment: A systematic review. Sensors, 24(1), 298, DOI: 10.3390/s24010298.
- Hart S.G., Staveland L.E., 1988, Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: Advances in Psychology, 52, 139–183, Elsevier.
- Hertzum M., 2021, Reference values and subscale patterns for the task load index (TLX): a meta-analytic review. Ergonomics, 64(7), 869–878.
- Inegbedion H., Inegbedion E., Peter A., Harry L., 2020, Perception of workload balance and employee job satisfaction in work organisations. Heliyon, 6(1), e03160.
- Karwowski W., 2005, Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems. Ergonomics, 48(5), 436–463, DOI: 10.1080/00140130400029167.
- Mathiassen S.E., 2006, Diversity and variation in biomechanical exposure: what is it, and why would we like to know? Applied Ergonomics, 37(4), 419–427.
- Mehdizadeh A., Vinel A., Hu Q., Schall M.C. Jr, Gallagher S., Sesek R.F., 2020, Job rotation and work-related musculoskeletal disorders: a fatigue-failure perspective. Ergonomics, 63(4), 461–476.
- Miyake S., 2001, Multivariate workload evaluation combining physiological and subjective measures. International Journal of Psychophysiology, 40(3), 233–238.
- Mlekus L., Maier G.W., 2021, More hype than substance? A meta-analysis on job and task rotation. Frontiers in Psychology, 12, 633530.
- Otto A., Battaïa O., 2017, Reducing physical ergonomic risks at assembly lines by line balancing and job rotation: A survey. Computers & Industrial Engineering, 111, 467–480, DOI: 10.1016/j.cie.2017.04.011.
- Padula R.S., Comper M.L.C., Sparer E.H., Dennerlein J.T., 2017, Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review. Applied Ergonomics, 58, 386–397.
- Schall M.C. Jr, Chen H., Cavuoto L., 2022, Wearable inertial sensors for objective kinematic assessments: A brief overview. Journal of Occupational and Environmental Hygiene, 19(9), 501–508.
- Wahyudi M.A., Dania W.A.P., Silalahi R.L.R., 2015, Work posture analysis of manual material handling using OWAS method. Agriculture and Agricultural Science Procedia, 3, 195–199.